

REMARKS

Claims 1-15, 19-36, and 38-45 remain pending. Claims 1, 14, 21, 34, 44, and 45 are in independent form. Claim 34 has been amended.

Applicant submits herewith sworn English translations of Japanese Application Nos. 2000/265819, filed September 1, 2000, and 2001-255145, filed August 24, 2001, from which the present application claims priority.¹ The filing of the sworn translations remove U.S. Patent Application Publication No. 2002/0031972 (Kitamura et al.), which has a filing date of August 29, 2001, as a reference against the claims supported by the Japanese priority applications.

All of the pending claims are believed to be patentable for the reasons given in the Remarks section of the Amendment filed on July 23, 2003. Accordingly, Applicant respectfully requests favorable reconsideration and early passage to issue of the present application.

An Information Disclosure Statement will be filed shortly. If the Examiner takes this case up for action prior to receiving that paper, he is respectfully requested to contact the undersigned representative.

^{1/} Declarations stating that the English translations are accurate are submitted herewith.

Applicant's undersigned attorney may be reached in our New York office by telephone at (212) 218-2100. All correspondence should continue to be directed to our below listed address.

Respectfully submitted,



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D E C L A R A T I O N

I, NOBUAKI KATO, a Japanese Patent Attorney registered No.08517, of Okabe International Patent Office at No. 602, Fuji Bldg., 2-3, Marunouchi 3-chome, Chiyoda-ku, Tokyo, Japan, hereby declare that I have a thorough knowledge of Japanese and English languages, and that the attached pages contain a correct translation into English of the priority documents of Japanese Patent Application No. 2001-255145 filed on August 24, 2001 in the name of CANON KABUSHIKI KAISHA.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that wilful false statements and the like so made, are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such wilful false statements may jeopardize the validity of the application or any patent issuing thereon.

Signed this 19th day of August, 2003



NOBUAKI KATO

PATENT OFFICE
JAPANESE GOVERNMENT

This is to certify that the annexed is a true copy
of the following application as filed with this Office.

Date of Application: August 24, 2001

Application Number: Japanese Patent Application
No. 2001-255145

Applicant(s): CANON KABUSHIKI KAISHA

September 18, 2001

Commissioner: KOZO OIKAWA
Patent Office

(seal)

Certificate No. 2001-3085916

2001-255145

[Name of the Document]	Patent Application
[Reference No.]	4519088
[Date]	August 24, 2001
[Address to]	Commissioner of Patent Office KOZO OIKAWA
[International Classification]	H01J 1/30 H01J 31/12 H01J 9/00
[Title of the Invention]	ELECTRON-EMITTING DEVICE, ELECTRON-EMITTING APPRATUS, LIGHT-EMITTING APPARARUS AND IMAGE DISPLAY APPARATUS
[Number of Claims]	39
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[Claim to priority Based on the Earliest Application]

[Application Number]	2000-265819
[Date of Application]	September 1, 2000

[Indication of Official Fee]

[Prepayment Ledger No.]	066073
[Amount]	21000

[List of Filed Materials]

[Material]	Specification	1
[Mateiral]	Drawing	1
[Material]	Abstract	1
[Proof Required]	Required	

[Name of the Document] Specification

[Title of the Invention] Electron-Emitting Device,
Electron-Emitting Apparatus, Light-Emitting Apparatus
And Image Display Apparatus

5 [What is claimed is]

 [Claim 1]

 An electron-emitting apparatus including:

 a first electrode and a second electrode disposed
on a surface of a substrate;

10 first voltage application means for applying to
said second electrode a potential higher than a
potential applied to said first electrode;

 an electron-emitting member disposed on said
first electrode;

15 a third electrode disposed so as to face said
substrate, electrons emitted from said electron-
emitting member reaching said third electrode; and

 second voltage application means for applying to
said third electrode a potential higher than each of
20 the potentials applied to said first and second
electrodes, said apparatus characterized in that

 a surface of said electron-emitting member is
placed between a plane containing a surface of said
second electrode and substantially parallel to the
25 surface of said substrate and a plane containing a

surface of said third electrode and substantially parallel to the surface of said substrate, and

when the distance between said second electrode and said first electrode is d ; the potential difference applied between said second electrode and said first electrode by said first voltage application means is V_1 ; the distance between said third electrode and said substrate is H ; and the potential difference between the potential applied to said third electrode by said second voltage application means and the potential applied to said first electrode by said first voltage application means is V_2 , then an electric field $E_1 = V_1/d$ is within the range from 1 to 50 times an electric field $E_2 = V_2/H$.

[Claim 2]

An apparatus according to claim 1, wherein the thickness of said first electrode is larger than the thickness of said second electrode.

[Claim 3]

An apparatus according to claim 1, wherein said electron-emitting member extends from a position on said first electrode to a position on said substrate between said first electrode and said second electrode.

[Claim 4]

An apparatus according to claim 1, wherein said

substrate has a difference in level between said second electrode and said first electrode, and said third electrode is closer to said first electrode than to said second electrode.

5 [Claim 5]

 An apparatus according to any one of claims 1 to 4, wherein said electron-emitting member is made of a material containing carbon as a main ingredient.

 [Claim 6]

10 An apparatus according to claim 5, wherein said material containing carbon as a main ingredient comprises fibrous carbon.

 [Claim 7]

 An apparatus according to claim 6, wherein said
15 fibrous carbon comprises a graphite nanofiber, a carbon nanotube, amorphous carbon, or a mixture of at least two of these materials.

 [Claim 8]

 An apparatus according to claim 7, wherein said
20 fibrous carbon is grown by means of catalytic particles.

 [Claim 9]

 An apparatus according to claim 8, wherein said catalytic particles are made of Pd, Ni, Fe, Co or an
25 alloy of at least two of these metals.

[Claim 10]

An apparatus according to any one of claims 1 to
9, wherein a plurality of said first electrodes and a
plurality of said second electrodes are disposed on the
5 surface of said substrate.

[Claim 11]

An apparatus according to claim 10, wherein said
plurality of first electrodes and said plurality of
second electrodes are electrically connected to wiring
10 in matrix form.

[Claim 12]

An apparatus according to claim 10, wherein a
light-emitting member capable of emitting light when
irradiated with electrons emitted from said electron-
15 emitting member is provided on said third electrode.

[Claim 13]

An image display apparatus, characterized by an
electron-emitting apparatus according to claim 12, said
apparatus displaying an image by means of light
20 emission of said light-emitting member.

[Claim 14]

An electron-emitting device including:
a fiber containing carbon as a main ingredient;
and
25 an electrode for controlling emission of

electrodes from said fiber containing carbon as a main ingredient, said device characterized in that

said fiber containing carbon as a main ingredient has a plurality of graphenes layered so as not to be
5 parallel to the axis direction of said fiber.

[Claim 15]

An electron-emitting device according to claim 14, wherein the plurality of graphenes is substantially parallel to each other.

10 [Claim 16]

An electron-emitting device according to claim 14, further characterized by a cathode electrode, wherein said fiber containing carbon as a main ingredient is provided on said cathode electrode and is
15 electrically connected to said cathode electrode.

[Claim 17]

An electron-emitting device according to any one of claims 14 to 16, wherein said cathode electrode and said electrode for controlling emission of electrons
20 are disposed on one substrate, a gap being formed between said cathode electrode and said electrode for controlling emission of electrons.

[Claim 18]

An electron-emitting device according to any one
25 of claims 14 to 17, said device characterized by a

plurality of said fibers containing carbon as a main ingredient.

[Claim 19]

5 A light-emitting apparatus, characterized by an electron-emitting device according to any one of claims 14 to 18, and a light-emitting member emitting light owing to electrons emitted from said electron-emitting device.

[Claim 20]

10 An image display apparatus including a plurality of electron-emitting devices and a light emitting member capable of emitting light when irradiated with electrons emitted from some of said plurality of electron-emitting devices, the apparatus characterized
15 in that each of said plurality of electron-emitting devices is constituted by the electron-emitting device according to any one of claims 14 to 18.

[Claim 21]

An electron-emitting apparatus including:
20 a first electrode and a second electrode disposed on a surface of a substrate;

first voltage application means for applying to said second electrode a potential higher than a potential applied to said first electrode;

25 a plurality of fibers disposed on said first

electrode, said fibers containing carbon as a main constituent;

a third electrode disposed so as to face said substrate, electrons emitted from said fibers reaching
5 said third electrode; and

second voltage application means for applying to said third electrode a potential higher than each of the potentials applied to said first and second electrodes, said apparatus characterized in that

10 a surface region of said fibers is placed between a plane containing a surface of said second electrode and substantially parallel to the surface of said substrate and a plane containing a surface of said third electrode and substantially parallel to the
15 surface of said substrate.

[Claim 22]

An electron-emitting apparatus according to claim 21, wherein when the distance between said second electrode and said first electrode is d ; the potential
20 difference applied between said second electrode and said first electrode by said first voltage application means is V_1 ; the distance between said third electrode and said substrate is H ; and the potential difference between the potential applied to said third electrode
25 by said second voltage application means and the

potential applied to said first electrode is V_2 , then an electric field $E_1 = V_1/d$ is within the range from 1 to 50 times an electric field $E_2 = V_2/H$.

[Claim 23]

5 An apparatus according to claim 21 or 22, wherein each of said fibers having carbon as a main ingredient comprises a carbon nanotube.

[Claim 24]

10 An apparatus according to any one of claims 21 to 23, wherein each of said fibers containing carbon as a main ingredient comprises a plurality of graphenes stacked so as to be nonparallel to the axis direction of said fiber.

[Claim 25]

15 An apparatus according to claim 21, wherein a material more effective in accelerating deposition of carbon than the material of said first electrode is provided between said fibers having carbon as a main ingredient and said cathode.

20 [Claim 26]

 An apparatus according to claim 25, wherein said material effective in accelerating deposition of carbon comprises Pd, Ni, Fe, Co or an alloy formed of at least two of said metals.

25 [Claim 27]

An apparatus according to claim 25, wherein said material effective in accelerating deposition of carbon is provided in the form of a plurality of particles on said first electrode.

5 [Claim 28]

An apparatus according to claim 27, wherein said plurality of particles is provided on said first electrode at a density of 10^{10} particles/cm² or higher.

[Claim 29]

10 An apparatus according to any one of claims 21 to 28, wherein the thickness of said first electrode is larger than the thickness of said second electrode.

[Claim 30]

15 An apparatus according to any one of claims 21 to 29, wherein a plurality of said first electrodes and a plurality of said second electrodes are disposed on the surface of said substrate.

[Claim 31]

20 An apparatus according to claim 30, wherein said plurality of first electrodes and said plurality of second electrodes are electrically connected to wiring in matrix form.

[Claim 32]

25 An apparatus according to claim 30, wherein a light-emitting member emitting light owing to

irradiation of electrons emitted from said electron-emitting member is provided on said third electrode.

[Claim 33]

An image display apparatus, characterized by an
5 electron-emitting apparatus according to claim 32, said apparatus displaying an image by means of light emission of said light-emitting member.

[Claim 34]

An electron-emitting device including:

10 a first electrode and a second electrode disposed on a surface of a substrate, a gap being formed between said first and second electrodes; and

a fiber provided on said first electrode, said fiber containing carbon as a main ingredient, said
15 device characterized in that

said second electrode comprises an electrode for controlling emission of electrodes from said fiber containing carbon as a main ingredient, and

said fiber containing carbon as a main ingredient
20 comprises graphene.

[Claim 35]

An electron-emitting device according to claim 34, wherein the distance between an extreme end of said fiber and the surface of said substrate is larger than
25 the distance between the surface of said second

electrode and the surface of said substrate.

[Claim 36]

An electron-emitting device according to claim 34
or 35, wherein said graphene comprises cylindrical
5 graphene.

[Claim 37]

An electron-emitting device according to any one
of claims 34 to 36, wherein said electron-emitting
device comprises a plurality of fibers containing
10 carbon as a main ingredient.

[Claim 38]

A light-emitting apparatus, characterized by an
electron-emitting device according to any one of claims
34 to 37, and a light-emitting member emitting light
15 owing to electrons emitted from said electron-emitting
device.

[Claim 39]

An image display apparatus including a plurality
of electron-emitting devices and a light emitting
20 member emitting light owing to irradiation with
electrons emitted from said plurality of electron-
emitting devices, said apparatus characterized in that
each of said plurality of electron-emitting devices is
constituted by an electron-emitting device according to
25 any one of claims 34 to 37.

[Detailed Description of the Invention]

[0001]

[Field of the Industrial Application]

The present invention relates to an electron-
5 emitting device, an electron-emitting apparatus, a
light-emitting apparatus and an image display
apparatus. The present invention also relates to a
display apparatus such as a television broadcast
display, and a display for use in a video conference
10 system, a computer display or the like.

[0002]

[Prior Art]

A field emission (FE) type of electron-emitting
device which emits electrons from a surface of a metal
15 when a strong electric field of 10^6 V/cm or higher is
applied to the metal, and which is one of the known
cold cathode electron sources, is attracting attention.

[0003]

If the FE-type cold electron source is put to
20 practical use, a thin emissive type image display
apparatus can be realized. The FE-type cold electron
source also contributes to reductions in power
consumption and weight of an image display apparatus.

[0004]

25 Fig. 13 shows a vertical FE-type cold electron

source structure formed of a substrate 131, an emitter electrode 132, an insulating layer 133, an emitter 135, and an anode 136. The shape of an electron beam with which the anode is irradiated is indicated by 137.

5 This structure is of a Spindt type such that an opening is formed in the insulating layer 133 and the gate electrode 134 provided on the cathode electrode 132, and the emitter 135 having a conical shape is placed in the opening. (This type of structure is disclosed by,
10 for example, C.A. Spindt, "Physical Properties of thin-film field emission cathodes with molybdenum cones", J. Appl. Phys., 47, 5248 (1976).)

[0005]

Fig. 14 shows a lateral FE structure formed of a
15 substrate 141, an emitter electrode 142, an insulating layer 143, an emitter 145, and an anode 146. The shape of an electron beam with which the anode is irradiated is indicated by 147. The emitter 145 having an acute extreme end and the gate electrode 144 for drawing out
20 electrons from the extreme end of the emitter are disposed above and parallel to the substrate, and the collector (anode) is formed above the gate electrode and the emitter electrode remote from the substrate (see USP 4,728,851, USP 4,904,895, etc.).

25 [0006]

Also, Japanese Patent Application Laid-open No.
8-115652 discloses an electron-emitting device using
fibrous carbon which is deposited in a narrow gap by
performing thermal cracking of an organic chemical
5 compound gas on a catalyst metal.

[0007]

[Problems to be solved by the Invention]

In an image display apparatus using one of the
above-described FE-type electron sources, an electron
10 beam spot is obtained which has a size (hereinafter
referred to as "beam diameter") depending on the
distance H between the electron source and the
phosphor, the anode voltage V_a , and the device drive
voltage V_f . The beam diameter is smaller than a
15 millimeter and the image display apparatus has
sufficiently high resolution.

[0008]

In recent years, however, there has been a
tendency to require higher resolution of image display
20 apparatuses.

[0009]

Further, with the increase in the number of
display pixels, power consumption during driving due to
the device capacitance of electron-emitting devices is
25 increased. Therefore there is a need to reduce the

device capacitance and the drive voltage and to improve the efficiency of electron-emitting devices.

[0010]

In the above-described Spindt type of electron
5 source, the gate is laminated on the substrate with the insulating layer interposed therebetween, so that parasitic capacitances are produced between large capacitances and a multiplicity of emitters. Moreover, the drive voltage is high, several ten to several
10 hundred volts, and capacitive power consumption is disadvantageously large because of the specific structure.

[0011]

Also, since the beam of electrons drawn out
15 spreads out, there is a need for a focusing electrode for limiting spreading of the beam. For example, Japanese Patent Application Laid-open No. 7-6714 discloses a method of converging electron trajectories by disposing an electrode for focusing electrons. This
20 method, however, has the problem of an increase in complexity of the manufacturing process, a reduction in electron emission efficiency, etc., due to the addition of the focusing electrode.

[0012]

25 In ordinary lateral FE electron sources,

electrons emitted from the cathode are liable to impinge on the opposed gate electrode. Therefore the structure of lateral FE electron sources has the problem of a reduction in the efficiency (the ratio of
5 the electron current flowing through the gate and the electron current reaching the anode) and considerable spreading of the beam shape on the anode.

[0013]

In view of the above-described problems, an
10 object of the present invention is to provide an electron-emitting device in which the specific capacitance is reduced, which has a lower drive voltage, and which is capable of obtaining a finer electron beam by controlling the trajectory of emitted
15 electrons.

[0014]

[Means for solving the Problems]

To achieve the above-described object, the present invention is an electron-emitting apparatus
20 including: a first electrode and a second electrode disposed on a surface of a substrate; first voltage application means for applying to the second electrode a potential higher than a potential applied to the first electrode; an electron-emitting member disposed
25 on the first electrode; a third electrode disposed so

as to face the substrate, electrons emitted from the electron-emitting member reaching the third electrode; and second voltage application means for applying to the third electrode a potential higher than each of the
5 potentials applied to the first and second electrodes, the apparatus characterized in that a surface of the electron-emitting member is placed between a plane containing a surface of the second electrode and substantially parallel to the surface of the substrate
10 and a plane containing a surface of the third electrode and substantially parallel to the surface of the substrate, and when the distance between the second electrode and the first electrode is d ; the potential difference applied between the second electrode and the
15 first electrode by the first voltage application means is V_1 ; the distance between the third electrode and the substrate is H ; and the potential difference between the potential applied to the third electrode by the second voltage application means and the potential
20 applied to the first electrode by the first voltage application means is V_2 , then an electric field $E_1 = V_1/d$ is within the range from 1 to 50 times an electric field $E_2 = V_2/H$.

[0015]

25 Moreover, the apparatus is characterized in that

the thickness of the first electrode is larger than the thickness of the second electrode.

[0016]

Moreover, the apparatus is characterized in that
5 the electron-emitting member extends from a position on the first electrode to a position on the substrate between the first electrode and the second electrode.

[0017]

Moreover, the apparatus is characterized in that
10 the substrate has a difference in level between the second electrode and the first electrode, and the third electrode is closer to the first electrode than to the second electrode.

[0018]

15 Moreover, the apparatus is characterized in that the electron-emitting member is made of a material containing carbon as a main ingredient.

[0019]

Moreover, the apparatus is characterized in that
20 the material containing carbon as a main ingredient comprises fibrous carbon.

[0020]

Moreover, the apparatus is characterized in that the fibrous carbon comprises a graphite nanofiber, a
25 carbon nanotube, amorphous carbon, or a mixture of at

least two of these materials.

[0021]

Moreover, the apparatus is characterized in that the fibrous carbon is grown by means of catalytic
5 particles.

[0022]

Moreover, the apparatus is characterized in that the catalytic particles are made of Pd, Ni, Fe, Co or an alloy of at least two of these metals.

10 [0023]

Moreover, the apparatus is characterized in that a plurality of the first electrodes and a plurality of the second electrodes are disposed on the surface of the substrate.

15 [0024]

Moreover, the apparatus is characterized in that the plurality of first electrodes and the plurality of second electrodes are electrically connected to wiring in matrix form.

20 [0025]

Moreover, the apparatus is characterized in that a light-emitting member capable of emitting light when irradiated with electrons emitted from the electron-emitting member is provided on the third electrode.

25 [0026]

Moreover, the present invention may be configured as an image display apparatus characterized by the electron-emitting apparatus, the apparatus displaying an image by means of light emission of the light-emitting member.

[0027]

Moreover, the present invention is an electron-emitting device including: a fiber containing carbon as a main ingredient; and an electrode for controlling emission of electrodes from the fiber containing carbon as a main ingredient, the device characterized in that the fiber containing carbon as a main ingredient has a plurality of graphenes layered so as not to be parallel to the axis direction of the fiber.

[0028]

Moreover, the electron-emitting device is characterized in that the plurality of graphenes is substantially parallel to each other.

[0029]

Moreover, the electron-emitting device is further characterized by a cathode electrode, wherein the fiber containing carbon as a main ingredient is provided on the cathode electrode and is electrically connected to the cathode electrode.

[0030]

Moreover, the electron-emitting device is characterized in that the cathode electrode and the electrode for controlling emission of electrons are disposed on one substrate, a gap being formed between
5 the cathode electrode and the electrode for controlling emission of electrons.

[0031]

Moreover, the electron-emitting device is characterized by a plurality of the fibers containing
10 carbon as a main ingredient.

[0032]

Moreover, the present invention can be configured as a light-emitting apparatus characterized by any of the electron-emitting devices described above, and a
15 light-emitting member emitting light owing to electrons emitted from the electron-emitting device.

[0033]

Moreover, the present invention is an image display apparatus including a plurality of electron-
20 emitting devices and a light emitting member capable of emitting light when irradiated with electrons emitted from some of the plurality of electron-emitting devices, the apparatus characterized in that each of the plurality of electron-emitting devices is
25 constituted by any of the electron-emitting devices

described above.

[0034]

Moreover, the present invention is an electron-emitting apparatus including: a first electrode and a
5 second electrode disposed on a surface of a substrate;
first voltage application means for applying to the
second electrode a potential higher than a potential
applied to the first electrode; a plurality of fibers
disposed on the first electrode, the fibers containing
10 carbon as a main constituent; a third electrode
disposed so as to face the substrate, electrons emitted
from the fibers reaching the third electrode; and
second voltage application means for applying to the
third electrode a potential higher than each of the
15 potentials applied to the first and second electrodes,
the apparatus characterized in that a surface region of
the fibers is placed between a plane containing a
surface of the second electrode and substantially
parallel to the surface of the substrate and a plane
20 containing a surface of the third electrode and
substantially parallel to the surface of the substrate.

[0035]

Moreover, the electron-emitting apparatus is
characterized in that when the distance between the
25 second electrode and the first electrode is d ; the

potential difference applied between the second
electrode and the first electrode by the first voltage
application means is V_1 ; the distance between the third
electrode and the substrate is H ; and the potential
5 difference between the potential applied to the third
electrode by the second voltage application means and
the potential applied to the first electrode is V_2 ,
then an electric field $E_1 = V_1/d$ is within the range
from 1 to 50 times an electric field $E_2 = V_2/H$.

10 [0036]

Moreover, the apparatus is characterized in that
each of the fibers having carbon as a main ingredient
comprises a carbon nanotube.

[0037]

15 Moreover, the apparatus is characterized in that
each of the fibers containing carbon as a main
ingredient comprises a plurality of graphenes stacked
so as to be nonparallel to the axis direction of the
fiber.

20 [0038]

Moreover, the apparatus is characterized in that
a material more effective in accelerating deposition of
carbon than the material of the first electrode is
provided between the fibers having carbon as a main
25 ingredient and the cathode.

[0039]

Moreover, the apparatus is characterized in that the material effective in accelerating deposition of carbon comprises Pd, Ni, Fe, Co or an alloy formed of
5 at least two of the metals.

[0040]

Moreover, the apparatus is characterized in that the material effective in accelerating deposition of carbon is provided in the form of a plurality of
10 particles on the first electrode.

[0041]

Moreover, the apparatus is characterized in that the plurality of particles is provided on the first electrode at a density of 10^{10} particles/cm² or higher.

15 [0042]

Moreover, the apparatus is characterized in that the thickness of the first electrode is larger than the thickness of the second electrode.

[0043]

20 Moreover, the apparatus is characterized in that a plurality of the first electrodes and a plurality of the second electrodes are disposed on the surface of the substrate.

[0044]

25 Moreover, the apparatus is characterized in that

the plurality of first electrodes and the plurality of second electrodes are electrically connected to wiring in matrix form.

[0045]

5 Moreover, the apparatus is characterized in that a light-emitting member emitting light owing to irradiation of electrons emitted from the electron-emitting member is provided on the third electrode.

[0046]

10 Moreover, the present invention can be configured as an image display apparatus characterized by the electron-emitting apparatus described above, the apparatus displaying an image by means of light emission of the light-emitting member.

15 [0047]

 Moreover, the present invention is an electron-emitting device including: a first electrode and a second electrode disposed on a surface of a substrate, a gap being formed between the first and second
20 electrodes; and a fiber provided on the first electrode, the fiber containing carbon as a main ingredient, the device characterized in that the second electrode comprises an electrode for controlling emission of electrodes from the fiber containing carbon
25 as a main ingredient, and the fiber containing carbon

as a main ingredient comprises graphene.

[0048]

Moreover, the electron-emitting device is characterized in that the distance between an extreme
5 end of the fiber and the surface of the substrate is larger than the distance between the surface of the second electrode and the surface of the substrate.

[0049]

Moreover, the electron-emitting device is
10 characterized in that the graphene comprises cylindrical graphene.

[0050]

Moreover, the electron-emitting device is characterized in that the electron-emitting device
15 comprises a plurality of fibers containing carbon as a main ingredient.

[0051]

Moreover, the present invention can be configured as a light-emitting apparatus characterized by the
20 electron-emitting device described above and a light-emitting member emitting light owing to electrons emitted from the electron-emitting device.

[0052]

Moreover, the present invention can be configured
25 as an image display apparatus including a plurality of

electron-emitting devices and a light emitting member emitting light owing to irradiation with electrons emitted from the plurality of electron-emitting devices.

5 [0053]

The electron-emitting device of the present invention can stably emit electrons in a low vacuum degree at an increased rate for a long time period.

[0054]

10 According to the present invention, a light-emitting member is provided on the anode in the electron-emitting apparatus or above the electron-emitting device to form a light-emitting device, an image display apparatus or the like capable of
15 operating in a low vacuum degree and effecting high-luminance emission/display for a long time period with stability.

[0055]

[Embodiments of the Invention]

20 Preferred embodiments of the present invention will be described in detail with reference to the accompanying drawings. The description of components of the embodiments made below with respect to the size, material and shape of the components and the relative
25 positions of the components is not intended to limit

the scope of the present invention except for particular mention of specified details.

[0056]

The operating voltage V_f of FE devices is
5 generally determined by the electric field at an
extreme end of an emitter obtained from the Poisson
equation and by the current density of electron
emission current according to the relational expression
called "Fowler-Nordheim equation" with a work function
10 of the electric field and the emitter portion used as a
parameter.

[0057]

A stronger electric field is obtained as the
electric field necessary for emission of electrons as
15 the distance D between the emitter extreme end and the
gate electrode is smaller or the radius r of the
emitter extreme end is smaller.

[0058]

On the other hand, the maximum size X_d in the X-
20 direction of the electron beam obtained on the anode
(e.g., the maximum reach from the center of the
circular beam shape 137 shown in Fig. 13) is expressed
in such a form as to be proportional to (V_f/V_a) in
simple calculation.

25 [0059]

As is apparent from this relationship, an increase in V_f results in an increase in beam diameter.

[0060]

Consequently, there is a need to minimize the distance D and the radius of curvature r in order to reduce V_f .

[0061]

Beam shapes in conventional arrangements will be described with reference to Figs. 13 and 14. In Figs. 13 and 14, substrates which are corresponding components of the two arrangements are indicated by 131 and 141; emitter electrodes by 132 and 142; insulating layers by 133 and 143; emitters by 135 and 145; anodes by 136 and 146; the shapes of electron beams with which the anodes are irradiated by 137 and 147.

[0062]

In the case of the Spindt type described above with reference to Fig. 13, when V_f is applied between the emitter 135 and the gate 134, the strength of the electric field at the extreme end of the projection of the emitter 135 is increased and electrons are thereby taken out of a conical emitter portion about the extreme end into the vacuum.

[0063]

The electric field at the extreme end of the

emitter is formed based on the shape of the extreme end
of the emitter to have a certain finite area on the
same, so that electrons are perpendicularly drawn out
from the finite emitter extreme end area according to
5 the potential.

[0064]

Simultaneously, other electrons are emitted at
various angles. Electrons emitted at larger angles are
necessarily drawn toward the gate.

10 [0065]

As a result, if the gate is formed so as to have
a circular opening, the distribution of electrons on
the anode 136 shown in Fig. 13 forms a substantially
circular beam shape 137. That is, the shape of the
15 beam obtained is closely related to the shape of the
drawing gate and to the distance between the gate and
the emitter.

[0066]

In the case of the lateral FE electron source
20 (Fig. 14) in which electrons are drawn out generally
along one direction, an extremely strong electric field
substantially parallel to the surface of the substrate
141 (lateral electric field) is produced between the
emitter 145 and the gate 144, so that part 149 of
25 electrons emitted from the emitter 145 are drawn into

the vacuum above the gate 144 while the other electrons are taken into the gate electrode 144.

[0067]

In the arrangement shown in Fig. 14, electric
5 field vectors toward the anode 146 differ in direction from those causing emission of electrons (the electric field from the emitter 145 toward the gate 144).

Therefore the distribution of electrons (beam spot) formed by emitted electrons on the anode 146 is
10 increased.

[0068]

The electric field of electrons drawn out from the emitter electrode 145 (referred to as "lateral electric field" in the following description for
15 convenience sake while the electric field strengthening effect of the emitter configuration is ignored) and the electric field toward the anode (referred to as "vertical electric field" in the following description) will further be described.

20 [0069]

The "lateral electric field" can also be expressed as "electric field in a direction substantially parallel to the surface of substrate 131 (141)" in the arrangement shown in Fig. 13 or 14. It
25 can also be expressed as "electric field in the

direction of opposition of gate 144 and emitter 145"
with respect to the arrangement shown in Fig. 14 in
particular.

[0070]

5 Also, the "vertical electric field" can also be
expressed as "electric field in a direction
substantially perpendicular to the surface of substrate
131 (141)" in the arrangement shown in Fig. 13 or 14,
or as "electric field in the direction in which the
10 substrate 131 (141) is opposed to the anode 136 (146)".

[0071]

 In the arrangement shown in Fig. 14, as described
above, electrons emitted from the emitter are first
drawn out by the lateral electric field, fly toward the
15 gate, and are then moved upward by the vertical
electric field to reach the anode.

[0072]

 Important factors of this effect are the ratio of
the strengths of the lateral and vertical electric
20 fields and the relative position of the electron
emission point.

[0073]

 When the lateral electric field is stronger than
the vertical electric field by an order of magnitude,
25 the trajectories of almost all of electrons drawn out

from the emitter are gradually bent by radial potential produced by the lateral electric field so that the electrons fly toward the gate. A part of the electrons impinging on the gate ejects again in a scattering
5 manner. After ejection, however, the electrons repeat scattering while spreading out along the gate by forming elliptical trajectories again and again and while being reduced in number when ejecting until they are caught by the vertical electric field. Only after
10 the scattered electrons have exceeded an equipotential line formed by the gate potential (which line may be called "stagnation point"), they are moved upward by the vertical electric field.

[0074]

15 When the lateral electric field and the vertical electric field are approximately equal in strength, the restraint imposed by the lateral electric field on electrons drawn out is reduced, although the trajectories of the electrons are bent by the radial
20 potential. In this case, therefore, electron trajectories appear along which electrons travel to be caught by the vertical electric field without impinging on the gate.

[0075]

25 It has been found that if the electron emission

position at which electrons are emitted from the emitter is shifted from the gate plane toward the anode plane (see Fig. 6), emitted electrons can form trajectories such as to be caught by the vertical electric field with substantially no possibility of impinging on the gate when the lateral electric field and the vertical electric field are approximately equal in strength, that is, the ratio of the strength of the lateral electric field to that of the vertical electric field is approximately 1 to 1.

[0076]

Also, a study made of the electric field ratio has shown that if the distance between the gate electrode 144 and the extreme end of the emitter electrode 145 is d ; the potential difference (between the gate electrode and the emitter electrode) when the device is driven is V_1 ; the distance between the anode and the substrate (element) is H ; and the potential difference between the anode and the cathode (emitter electrode) is V_2 , a trajectory along which electrons drawn out impinge on the gate is formed when the lateral electric field $E_1 = V_1/d$ is 50 times or more stronger than the vertical electric field $E_2 = V_2/H$.

[0077]

The inventor of the present invention has also

found that a height s (defined as the distance between a plane containing a portion of a gate electrode 2 surface and substantially parallel to a substrate 1 surface and a plane containing an electron-emitting member 4 surface and substantially parallel to the substrate 1 surface (see Fig. 6)) can be determined such that substantially no scattering occurs on the gate electrode 2. The height s depends on the ratio of the vertical electric field and the lateral electric field (vertical electric field strength/lateral electric field strength). As the vertical-lateral electric field ratio is lower, the height s is lower. AS the lateral electric field is stronger, the necessary height s is higher.

[0078]

The height set in a practical manufacturing process ranges from 10 nm to 10 μm .

[0079]

In the conventional arrangement shown in Fig. 14, the gate 144 and the emitter (142, 145) are formed flush with each other along a common plane and the lateral electric field is stronger than the vertical electric field by an order of magnitude, so that there is a considerable tendency to reduce, by impingement on the gate, the amount of electrons drawn out into the

vacuum.

[0080]

Further, in the conventional arrangement, the structure of the device is determined so as to increase
5 the strength of the electric field in the lateral direction, so that the electron distribution on the anode 146 spreads widely.

[0081]

As described above, to restrict the distribution
10 of electrons reaching the anode 146, it is necessary (1) to reduce the drive voltage (V_f), (2) to unidirectionally draw out electrons, (3) to consider the trajectory of electrons and, if scattering on the gate occurs, (4) to consider the electron scattering
15 mechanism (elastic scattering in particular).

[0082]

Therefore the present invention aims to provide an electron-emitting device in which the distribution of electrons with which the anode electrode surface is
20 irradiated is made finer, and in which the electron emission efficiency is improved (the amount of emitted electrons absorbed in the gate electrode is reduced).

[0083]

The structure of a novel electron-emitting device
25 in accordance with the present invention will now be

described below in detail.

[0084]

Fig. 1(a) is a schematic plan view showing an example of an electron-emitting device in accordance with the present invention. Fig. 1(b) is a cross-sectional view taken along the line A-A of Fig. 1(a). Fig. 6 is schematic cross-sectional view of the electron-emitting apparatus of the present invention in a state where the electron-emitting apparatus having an anode electrode disposed above the electron-emitting device of the present invention is being driven.

[0085]

In Figs. 1 and 6 are illustrated an insulating substrate 1, an extraction electrode 2 (also referred to as "gate electrode" or "second electrode"), a cathode electrode 3 (also referred to as "first electrode"), an electron-emitting material 4 provided on the cathode electrode 3 (also referred to as "electron-emitting member" or "emitter material"), and an anode electrode 61 (also referred to as "third electrode").

[0086]

In the electron-emitting apparatus of the present invention, if as shown in Figs. 1 and 6 the distance by which the cathode electrode 3 and the gate electrode 2

are spaced apart from each other is d ; the potential difference (the voltage between the cathode electrode 3 and the gate electrode 2) when the electron-emitting device is driven is V_f ; the distance between the anode electrode 61 and the surface of the substrate 1 on which the electron-emitting device is arranged is H ; and the potential difference between the anode electrode 61 and the cathode electrode 3 is V_a , an electric field produced to drive the device (lateral electric field): $E_1 = V_f/d$ is set within the range from 1 to 50 times an electric field between the anode and the cathode (vertical electric field): $E_2 = V_a/H$.
[0087]

The proportion of electrons impinging on the gate electrode 2 in electrons emitted from the cathode electrode 3 is reduced thereby. In this manner, a high-efficiency electron-emitting device capable of preventing an emitted electron beam from spreading out widely can be obtained.

[0088]

The "lateral electric field" referred to in the description of the present invention can also be expressed as "electric field in a direction substantially parallel to the surface of substrate 1".
It can also be expressed as "electric field in the

direction in which the gate 2 is opposed to the cathode electrode 3".

[0089]

Also, the "vertical electric field" referred to
5 in the description of the present invention can also be expressed as "electric field in a direction substantially perpendicular to the surface of substrate 1". It can also be expressed as "electric field in the direction in which the substrate 1 is opposed to the
10 anode electrode 61".

[0090]

Further, in the electron-emitting apparatus of the present invention, a plane containing the surface of the electron-emitting member 4 and substantially
15 parallel to the surface of the substrate 1 is spaced apart from a plane containing a portion of the surface of the gate electrode 2 and substantially parallel to the surface of the substrate 1 (see Fig. 6). In other words, in the electron-emitting apparatus of the
20 present invention, a plane containing the surface of the electron-emitting member 4 and substantially parallel to the surface of the substrate 1 is placed between the anode electrode 61 and a plane containing a portion of the surface of the gate electrode 2 and
25 substantially parallel to the substrate surface (see

Fig. 6).

[0091]

Further, in the electron-emitting device of the present invention, the electron-emitting member 4 is placed at a height s (defined as the distance between the plane containing a portion of the surface of gate electrode 2 and substantially parallel to the surface of substrate 1 and the plane containing the surface of electron-emitting member 4 and substantially parallel to the surface of substrate 1 (see Fig. 6)) such that substantially no scattering occurs on the gate electrode 2.

[0092]

The height s depends on the ratio of the vertical electric field and the lateral electric field (vertical electric field strength/lateral electric field strength). As the vertical-lateral electric field ratio is lower, the height s is lower. As the lateral electric field is stronger, the necessary height s is higher. Practically, the height is not less than 10 nm not more than 10 μm .

[0093]

Examples of the insulating substrate 1 are the following substrates whose surfaces are sufficiently cleansed: quartz glass; glass in which the content of

an impurity such as Na is reduced by partial substitution by K, for example; a laminate formed in such a manner that SiO₂ is laminated by sputtering or the like on soda lime glass, a silicon substrate or the like; and an insulating substrate made of a ceramic such as alumina.

[0094]

Each of the extraction electrode 2 and cathode electrode 3 is an electrically conductive member formed on the surface of the substrate 1 by an ordinary vacuum film forming technique, such as evaporation or sputtering, or a photolithography technique so as to face each other. The material of the electrodes 2 and 3 is selected from, for example, carbon, metals, nitrides of metals, carbides of metals, borides of metals, semiconductors, and metallic compounds of semiconductors. The thickness of the electrodes 2 and 3 is set within the range from several ten nanometers to several ten microns. Preferably, the material of the electrodes 2 and 3 is a heat resistant material formed of carbon, a metal, a nitride of a metal or a carbide of a metal.

[0095]

The material of the electrodes 2 and 3 constituting the electron-emitting device in accordance

with the present invention are disposed on the surface of the substrate 1. Needless to say, the extraction electrode 2 and the cathode electrode 3 are spaced apart from each other along a direction substantially parallel to the plane containing the surface of the substrate 1. In other words, the electron-emitting device is constructed so that the extraction electrode 2 and the cathode electrode 3 do not overlap each other.

10 [0096]

In particular, in the case of growth of fibrous carbon described below, the electrodes are preferably formed of silicon having conductivity, e.g., doped polysilicon or the like.

15 [0097]

If there is apprehension about, for example, a voltage drop due to the small thickness of the electrodes, or if a plurality of the electron-emitting devices are used in matrix form, a low-resistance wiring metallic material may be used to form suitable wiring portions on condition that it does not affect emission of electrons.

[0098]

The emitter material (electron-emitting member) 4 may be formed in such a manner that a film deposited by

an ordinary vacuum film forming method such as sputtering is worked into the shape of the emitter by using a technique such as reactive ion etching (RIE). Alternatively, it may be formed by growing needle
5 crystals or whiskers by seed growth in chemical vapor deposition (CVD). In the case of RIE, the control of the emitter shape depends on the kind of the substrate used, the kind of gas, the gas pressure (flow rate), the etching time, the energy for forming plasma, etc.

10 In a CVD forming process, the emitter shape is controlled by selecting the kind of the substrate, the kind of gas, the flow rate, the growth temperature, etc.

[0099]

15 Examples of the material used to form the emitter (electron-emitting member) 4 are carbides, such as TiC, ZrC, HfC, TaC, SiC, and WC, amorphous carbon, graphite, diamondlike carbon, carbon containing dispersed diamond, and carbon compounds.

20 [0100]

According to the present invention, fibrous carbon is particularly preferably used as the material of the emitter (electron-emitting member) 4. "Fibrous carbon" referred to in the description of the present
25 invention can also be expressed as "material in

columnar form containing carbon as a main constituent"
or "material in filament form containing carbon as a
main constituent". Further, "fibrous carbon" can also
be expressed as "fibers containing carbon as a main
5 constituent". More specifically, "fibrous carbon" in
accordance with the present invention comprises carbon
nanotubes, graphite nanofibers, and amorphous carbon
fibers. In particular, graphite nanofibers are most
preferred as electron-emitting member 4.

10 [0101]

The gap between the extraction electrode 2 and
the cathode electrode 3 and the drive voltage (the
voltage applied between the extraction electrode 2 and
the cathode electrode 3) may be determined so that the
15 value of the lateral electric field necessary for
emission of electrons from the cathode material used is
1 to 50 times larger than that of the vertical electric
field necessary for forming an image, as described
above.

20 [0102]

In a case where a light-emitting member such as a
phosphor is provided on the anode (anode electrode),
the necessary vertical electric field is, preferably,
within the 10^{-1} to 10 V/ μm range. For example, in a
25 case where the gap between the anode (anode electrode)

and the cathode electrode is 2 mm and 10 kV is applied between the anode electrode and the cathode electrode, the vertical electric field is 5 V/ μm . In this case, the emitter material (electron-emitting member) 4 to be
5 used has an electron-emitting electric field value of 5 V/ μm or higher. The gap and the drive voltage may be determined in correspondence with the selected electron-emitting electric field value.

[0103]

10 An example of a material having an electric field threshold of several V/ μm is fibrous carbon. Each of Figs. 11 and 12 shows an example of the configuration of fibrous carbon. In each of Figs. 11 and 12, the configuration is schematically shown at the optical
15 microscope level (to 1,000 times) in the left-hand section, at the scanning electron microscope level (to 30,000 times) in the middle section, and at the transmission electron microscope level (to 1,000,000 times) in the right-hand section.

20 [0104]

A graphene structure formed into a cylinder such as that shown in Fig. 11 is called a carbon nanotube (a multilayer cylindrical graphene structure is called a multiwall nanotube). Its threshold value is minimized
25 when the tube end is opened.

[0105]

The fibrous carbon shown in Fig. 12 may be produced at a comparatively low temperature. Fibrous carbon having such a configuration is composed of a graphene layered body (thus, it may be referred to as "graphite nanofiber", and has an amorphous structure whose ratio is increased with temperature). More specifically, "graphite nanofiber" designates a fibrous substance in which graphenes are layered (laminated) in the longitudinal direction thereof (in the axis direction of the fiber). In other words, graphite nanofiber is a fibrous substance in which a plurality of graphenes are arranged and layered (laminated) so as not to be parallel to the fiber axis, as shown in Fig. 12.

[0106]

On the other hand, a carbon nanotube is a fibrous substance in which graphenes are arranged (in cylindrical shape) around the longitudinal direction (fiber axis direction). In other words, it is a fibrous substance in which graphenes are arranged substantially parallel to the fiber axis.

[0107]

One layer of graphite is called "graphene" or "graphene sheet". More specifically, graphite is

formed in such a manner that carbon planes on which
carbon atoms are arrayed so as to form regular hexagons
close to each other by covalent bond in sp^2
hybridization are laid one on another while being
5 spaced by a distance of 3.354 Å. Each carbon plane is
called "graphene" or "graphene sheet".

[0108]

Each type of fibrous carbon has an electron
emission threshold value of about 1 to 10 V/ μm and is
10 therefore preferred as the material of the emitter
(electron-emitting member) 4 in accordance with the
present invention.

[0109]

In particular, electron-emitting devices using
15 graphite nanofibers, not limited to the device
structure of the present invention shown in Fig. 1,
etc., are capable of causing emission of electrons in a
low electric field to obtain a large emission current,
and can be readily manufactured to obtain as an
20 electron-emitting device having stable electron-
emitting characteristics. For example, such an
electron-emitting element can be obtained by forming
graphite nanofibers as an emitter and by providing an
electrode for controlling emission of electrons from
25 the emitter. Further, if a light emitting member

capable of emitting light when irradiated with
electrons emitted from graphite nanofibers is used, a
light emitting device such as a lamp can be formed.
Further, an image display apparatus may be constructed
5 by forming an array of a plurality of the above-
described electron-emitting devices and by preparing an
anode having a light emitting material such as a
phosphor. In the electron-emitting device, the light
emitting device or the image display apparatus using
10 above-described graphite nanofibers, stable emission of
electrons can be achieved without maintaining inside
the device or the apparatus an ultrahigh vacuum such as
that required in conventional electron-emitting
devices. Moreover, since electrons are emitted by a
15 low electric field, the device or apparatus can be
easily manufactured with improved reliability.

[0110]

The above-described fibrous carbon can be formed
by decomposing a hydrocarbon gas by using a catalyst (a
20 material for accelerating deposition of carbon). The
processes for forming carbon nanotubes and graphite
nanofibers differ in the kind of catalyst and
decomposition temperature.

[0111]

25 The catalytic material may be a material which is

used as a seed for forming fibrous carbon, and which is selected from Fe, Co, Pd, No, and alloys of some of these materials.

[0112]

5 In particular, if Pd or Ni is used, graphite nanofibers can be formed at a low temperature (not lower than 400°C). The necessary carbon nanotube forming temperature in the case of using Fe or Co is 800°C or higher. Also, the process of producing a
10 graphite nanofiber material by using Pd or Ni, which can be performed at a lower temperature, is preferred from the viewpoint of reducing the influence on other components and limiting the manufacturing cost.

[0113]

15 Further, the characteristic of Pd that resides in enabling oxides to be reduced by hydrogen at a low temperature (room temperature) may be utilized. That is, palladium oxide may be used as a seed forming material.

20 [0114]

 If hydrogen reduction using palladium oxide is performed, an initial agglomeration seed can be formed at a comparatively low temperature (equal to or lower than 200°C) without metallic film thermal agglomeration
25 or ultrafine particle forming/deposition conventionally

used as ordinary seed forming techniques.

[0115]

The above-mentioned hydrocarbon gas may be, for example, acetylene, ethylene, methane, propane, or
5 propylene. Further, CO or CO₂ gas or vapor of an organic solvent such as ethanol or acetone may be used in some case.

[0116]

In the device of the present invention, the
10 region where the emitter (electron-emitting member) exists will be referred to as "emitter region" regardless of contribution to emission of electrons.

[0117]

The position of the electron emission point
15 (electron-emitting portion) in the "emitter region" and the electron-emitting operation will be described with reference to Figs. 6 and 7.

[0118]

The electron-emitting device having the distance
20 between the cathode electrode 3 and the extraction electrode 2 to several microns was set in a vacuum apparatus 60 such as shown in Fig. 6. A sufficiently high degree of vacuum about 10^{-4} Pa was produced by a evacuating pump 65. A potential (voltage V_a) higher by
25 several kilovolts than that of the cathode electrode 3

and the extraction electrode was applied from a voltage source ("second voltage application means" or "second potential application means") to the anode (anode electrode) 61, which was placed so that the surface of the anode 61 is at the height H , which was several millimeters, from the surface of the substrate 1, as shown in Fig. 6. While the voltage V_a was applied between the cathode electrode 3 and the anode 61, the voltage applied to the anode may be a voltage from the ground potential. The substrate 1 and the anode 61 were positioned relative to each other so that their surfaces are parallel to each other.

[0119]

Between the cathode electrode 3 and the extraction electrode 2 of the electron-emitting device, a voltage of about several ten volts was applied as drive voltage V_f from a power supply (not shown) ("first voltage application means" or "first potential application means"). Device current I_f flowing between the electrodes 2 and 3 and electron emission current I_e flowing through the anode were measured.

[0120]

It is supposed that, during this operation, equipotential lines 63 are formed as shown in Fig. 6 (an electric field (the direction of an electric field)

substantially parallel to the surface of the substrate 1, and that the concentration of the electric field is maximized at the point on a portion of the electron-emitting member 4 closest to the anode and facing the gap, as indicated by 64. It is thought that electrons are emitted mainly from the portion of the electron-emitting material in the vicinity of this electric field concentration point, where the concentration of the electric field is maximized. An I_e characteristic such as shown in Fig. 7 was obtained. That is, I_e rises abruptly at a voltage about half the applied voltage. The I_f characteristic (not shown) was similar to the I_e characteristic but the value of I_f was sufficiently smaller than that of I_e .

[0121]

An electron source obtained by arranging a plurality of the electron-emitting devices in accordance with the present invention will be described with reference to Fig. 8. In Fig. 8 are illustrated an electron source substrate 81, X-direction wiring 82, Y-direction wiring 83, electron-emitting device 84 in accordance with the present invention, and a connecting conductor 85.

[0122]

X-direction wiring 82 has m conductors DX_1 ,

DX2, ... DXm, which may be constituted by, for example,
a conductive metal formed by vacuum evaporation,
printing, sputtering, or the like. The material, film
thickness, and width of the wiring are selected
5 according to a suitable design. Y-direction wiring 83
has n conductors DY1, DY2, ... DYn and is formed in the
same manner as X-direction wiring 82. An interlayer
insulating layer (not shown) is provided between the m
conductors of X-direction wiring 82 and the
10 n conductors of Y-direction wiring 83 to electrically
separate these conductors (each of m and n is a
positive integer).

[0123]

The interlayer insulating layer (not shown) is,
15 for example, a SiO₂ layer formed by vacuum evaporation,
printing, sputtering, or the like. For example, the
interlayer insulating film is formed in the desired
shape over the whole or part of the surface of the
substrate 81 on which X-direction wiring 82 has been
20 formed and the film thickness, material and fabrication
method are selected to ensure withstanding against the
potential difference at the intersections of the
conductors of X-direction wiring 82 and Y-direction
wiring 83 in particular. The conductors of X-direction
25 wiring 82 and Y-direction wiring 83 are respectively

extended outward as external terminals.

[0124]

Pairs of electrodes (not shown) constituting electron-emitting devices 84 are electrically connected to the m conductors of X-direction wiring 82 and the n conductors of Y-direction wiring 83 by connecting conductors 85 made of a conductive metal or the like.

[0125]

The materials forming wiring 82 and wiring 83, the material forming the connecting conductors 85 and the materials forming the pairs of device electrodes may be entirely constituted of common constituent elements or partially constituted of common constituent elements, or may be constituted of different constituent elements. These materials are selected from, for example, the above-described device electrode materials. If the materials of the device electrodes and the wiring materials are the same, the wiring conductors connected to the device electrodes can be considered to be device electrodes.

[0126]

A scanning signal application means (not shown) for applying scanning signals for selecting the rows of electron-emitting devices 84 arranged in the X-direction is connected to X-direction wiring 82. On

the other hand, a modulation signal generation means for modulating voltages applied to the columns of electron-emitting devices 84 arranged in the Y-direction according to input signals is connected to Y-direction wiring 83. The drive voltage applied to each electron-emitting device is supplied as a voltage corresponding to the difference between the scanning signal and the modulation signal applied to the element.

10 [0127]

In the above-described arrangement, each device can be selected by using the passive-matrix wiring to be driven independently.

[0128]

15 An image forming apparatus constructed by using an electron source having such a passive matrix array will be described with reference to Fig. 9. Fig. 9 schematically shows an example of the display panel of the image forming apparatus. Referring to Fig. 9, a plurality of electron-emitting devices is disposed on an electron source substrate 81, which is fixed on a rear plate 91. A face plate 96 has a glass substrate 93, a phosphor film 94 provided as a light emitting member on the internal surface of the glass substrate 20 93, a metal back (anode) 95, etc. The rear plate 91 25 93, a metal back (anode) 95, etc. The rear plate 91

and the face plate 96 are connected to a supporting frame 92 by using frit glass or the like. An envelope 97 is formed by being seal-bonded by baking in, for example, atmospheric air, a vacuum or in nitrogen in
5 the 400 to 500°C temperature range for 10 minutes or longer.

[0129]

The envelope 97, as described above, is constituted by the face plate 96, the supporting frame
10 92, and the rear plate 91. The rear plate 91 is provided mainly for the purpose of reinforcing the substrate 81. If the substrate 81 itself has sufficiently high strength, there is no need to separately provide the rear plate 91. That is, the
15 supporting frame 92 may be directly seal-bonded to the substrate 81 and the envelope 97 may be formed by the frame plate 96, the supporting frame 92 and the substrate 81. A supporting member (not shown) called a spacer may be provided between the face plate 96 and
20 the rear plate 91 to enable the envelope 97 to have a sufficiently high strength for resisting atmospheric pressure.

[0130]

[Examples]

25 Examples of the present invention will be

described below in detail.

[0131]

(Example 1)

Fig. 1(a) shows a top view of an electron-
5 emitting device fabricated in this example. Fig. 1(b)
is a cross-sectional view taken along the line A-A of
Fig. 1(a).

[0132]

Fig. 1 illustrates an insulating substrate 1, an
10 extraction electrode 2 (gate), a cathode electrode 3,
and an emitter material 4.

[0133]

In the following, the process of fabricating the
electron-emitting device of this example will be
15 described in detail by the use of Fig. 5.

[0134]

(Step 1)

A quartz substrate was used as substrate 1.
After sufficiently cleansing the substrate, a 5 nm
20 thick Ti film (not shown) and a 30 nm thick poly-Si
film (arsenic doped) were successively deposited by
sputtering on the substrate as gate electrode 2 and
cathode electrode 3.

[0135]

25 Next, a resist pattern was formed by

photolithography using a positive photoresist (AZ1500/
from Clariant Corporation).

[0136]

Thereafter, dry etching was performed on the
5 poly-Si (arsenic doped) layer and Ti layer with the
patterned photoresist used as a mask, CF₄ gas being used
to etch the Ti layer. An extraction electrode 2 and a
cathode 3 having a gap of 5 μm therebetween were
thereby formed (Fig. 5(a)).

10 [0137]

(Step 2)

Next, a Cr having a thickness of about 100 nm was
deposited on the entire substrate by electron beam (EB)
evaporation.

15 [0138]

A resist pattern was formed by photolithography
using a positive photoresist (AZ1500/ from Clariant
Corporation).

[0139]

20 An opening corresponding to a region (100 μm
square) where electron-emitting material 4 was to be
provided was formed on the cathode 3 with the patterned
photoresist used as a mask. Cr at the opening was
removed by using a cerium nitrate etching solution.

25 [0140]

After removing the resist, a complex solution prepared by adding isopropyl alcohol, etc., to a Pd complex was applied to the entire substrate by spin coating.

5 [0141]

After application of the solution, a heat treatment was performed in atmospheric air at 300°C to form a palladium oxide layer 51 having a thickness of about 10 nm. Thereafter, Cr was removed by using a cerium nitrate etching solution (Fig. 5(b)).

[0142]

(Step 3)

The substrate was baked at 200°C, atmospheric air was evacuated, and a heat treatment was then performed in 2% hydrogen flow diluted with nitrogen. At this stage, particles 52 having a diameter of about 3 to 10 nm were formed on the surface of the cathode electrode 3. The density of the particles at this stage was estimated at about 10^{11} to 10^{12} particles/cm² (Fig. 5(c)).

[0143]

(Step 4)

Subsequently, a heat treatment was performed in a 0.1% ethylene flow diluted with nitrogen at 500°C for 10 minutes. The state after the heat treatment was

observed with a scanning electron microscope to find that a multiplicity of fibrous carbon 4 having a diameter of about 10 to 25 nm and extending like fibers while curving or bending had been formed in the Pd-coated region. The thickness of the fibrous carbon layer was about 500 nm (Fig. 5(d)).

[0144]

This electron-emitting device was set in the vacuum apparatus 60 shown in Fig. 6. A sufficiently high vacuum of about 2×10^{-5} Pa was produced by the evacuating pump 62. Voltage $V_a = 10$ kV was applied as anode voltage to the anode 61 distanced by $H = 2$ mm from the device, as shown in Fig. 6. Also, a pulse voltage of $V_f = 20$ V was applied as drive voltage to the device. Device current I_f and electron emission current I_e thereby caused were measured.

[0145]

The I_f and I_e characteristics of the electron-emitting device were as shown in Fig. 7. That is, I_e rises abruptly at a voltage about half the applied voltage, and a current of about 1 μ A was measured as electron emission current I_e at a V_f value of 15 V. On the other hand, the I_f characteristic was similar to the I_e characteristic but the value of I_f was smaller than that of I_e by an order of magnitude or more.

[0146]

The obtained beam had a generally rectangular shape having a longer side along the Y-direction and a shorter side in the X-direction. The beam width was measured with respect to different gaps of 1 μm and 5 μm between the electrodes 2 and 3 while V_f was fixed at 15 V and the distance H to the anode was fixed at 2 mm. Table 1 shows the results of this measurement.

[0147]

10 Table 1

	$V_a = 5 \text{ kV}$	$V_a = 10 \text{ kV}$
Gap: 1 μm	60 μm in x-direction 170 μm in y-direction	30 μm in x-direction 150 μm in y-direction
Gap: 5 μm	93 μm in x-direction 170 μm in y-direction	72 μm in x-direction 150 μm in y-direction

[0148]

It was possible to change the necessary electric field for driving by changing the fibrous carbon growth conditions. In particular, the average particle size of Pd particles formed by reduction of palladium oxide is related to the diameter of fibrous carbon thereafter grown. It was possible to control the average Pd particle size through the Pd density in the Pd complex coating and the rotational speed of spin coating.

[0149]

The fibrous carbon of this electron-emitting device was observed with the transmission electron microscope to recognize a structure in which graphenes
5 are layered in the fiber axis direction, as shown in the right-hand section of Fig. 12. The graphene stacking intervals (in the Z-axis direction) resulting from heating at a lower temperature, about 500°C were indefinite and was 0.4 nm. As the heating temperature
10 was increased, the grating intervals became definite. The intervals resulting from heating at 700°C were 0.34 nm, which is close to 0.335 nm in graphite.

[0150]

(Example 2)

15 Fig. 2 shows a second example of the present invention.

[0151]

In this example, an electron-emitting device was fabricated in the same manner as that in the first
20 example except that the cathode electrode 3 corresponding to that in the first example had a thickness of 500 nm and fibrous carbon provided as electron-emitting material 4 had a thickness of 100 nm. Currents I_f and I_e in the fabricated electron-emitting
25 device were measured.

[0152]

In this device arrangement, the electron emission point was positively heightened (toward the anode) relative to the gate electrode by increasing the thickness of the cathode 3. Trajectories along which electrons impinge on the gate were thereby reduced, thereby preventing a reduction in efficiency and occurrence of a beam-thickening phenomenon.

[0153]

Also in this device arrangement, the electron emission current I_e at $V_f = 20V$ was about $1 \mu A$. On the other hand, the I_f characteristic was similar to the I_e characteristic but the value of I_f was smaller than that of I_e by two orders of magnitude.

[0154]

The results of measurement of the beam diameter in this example were substantially the same as those shown in Table 1.

[0155]

(Example 3)

Fig. 3 shows a third example of the present invention.

[0156]

In this example, in the step corresponding to step 2 in the first example, palladium oxide 51 was

provided on the cathode electrode 3 and in the gap between the electrodes 2 and 3. Pd oxide was provided in the gap in such a manner as to extend from the cathode 3 to a point near the midpoint of the gap.

5 Excepting step 2, this example is the same as the first example.

[0157]

The electric field in the electron-emitting device of this example was twice as strong as that in
10 the first example because the gap was reduced, thereby enabling the drive voltage to be reduced to about 8 V.

[0158]

(Example 4)

Fig. 4 shows a fourth example of the present
15 invention. In this example step 1 and step 2 described above with respect to the first example are changed as described below.

[0159]

(Step 1)

20 A quartz substrate was used as substrate 1. After sufficiently cleansing the substrate, a 5 nm thick Ti film and a 30 nm thick poly-Si film (arsenic doped) were successively deposited by sputtering on the substrate as cathode electrode 3.

25 [0160]

Next, a resist pattern was formed by photolithography using a positive photoresist (AZ1500/ from Clariant Corporation).

[0161]

5 Next, dry etching was performed on the poly-Si layer and Ti layer by using CF_4 gas, with the patterned photoresist used as a mask. Cathode electrode 3 was thereby formed.

[0162]

10 The quartz substrate was then etched to a depth of about 500 nm by using a mixed acid formed of hydrofluoric acid and ammonium fluoride.

[0163]

 Subsequently, a 5 nm thick Ti film and a 30 nm
15 thick Pt film were successively deposited on the substrate as gate electrode 2 by again performing sputtering. After removing the photoresist from the cathode, a resist pattern was again formed by using a positive photoresist (AZ1500/ from Clariant
20 Corporation) to form the gate electrode.

[0164]

 Next, dry etching was performed on the Pt layer and Ti layer by using Ar, with the patterned photoresist used as a mask. Electrode 2 was thereby
25 formed so that the step formed between the electrodes

functions as a gap.

[0165]

Next, a resist pattern was formed on the cathode,
a Ni film having a thickness of about 5 nm was formed
5 by resistance heating evaporation having a good
straight-in effect, and oxidation was thereafter
performed at 350°C for 30 minutes.

[0166]

This step was followed by the same steps as those
10 in the first example.

[0167]

The above-described device arrangement enabled
formation of a finer gap such that electrons were
effectively emitted at a lower voltage of about 6 V.

15 [0168]

Because the height of the electron-emitting
material 4 (film thickness) was increased relative to
that of the gate electrode, electrons were drawn out
not only from the upper portion of the electron-
20 emitting material 4 but also from an intermediate
portion. Thus, the arrangement in this example has the
effect of preventing a reduction in efficiency due to
impingement of electrons on the gate electrode and
occurrence of a beam-thickening phenomenon.

25 [0169]

(Example 5)

An electron source obtained by arranging a plurality of the electron-emitting devices fabricated the first example and an image forming apparatus using this electron source will be described with reference to Figs. 8, 9, and 10. In Fig. 8 are illustrated an electron source substrate 81, X-direction wiring 82, Y-direction wiring 83, electron-emitting devices 84 in accordance with the present invention, and connecting conductors 85.

[0170]

The electron source with matrix wiring shown in Fig. 8, in which the device capacitance is increased by arranging a plurality of electron-emitting devices, has a problem that, even when a short pulse produced by pulse-width modulation is applied, the waveform is dulled or distorted by capacitive components to cause failure to obtain the necessary grayscale level, for example. In this example, therefore, a structure is adopted in which an interlayer insulating layer is provided by the side of the electron-emitting region to limit the increase in capacitive components in regions other than the electron-emitting region.

[0171]

Referring to Fig. 8, X-direction wiring 82 has m

conductors DX1, DX2, ... DXm, which has a thickness of about 1 μm and a width of 300 μm , and which is formed of an aluminum wiring material by evaporation. The material, film thickness, and width of the wiring
5 conductors are selected according to a suitable design. Y-direction wiring 83 has n conductors DY1, DY2, ... DYn, which has a thickness of 5 μm and width of 100 μm , and which is formed in the same manner as X-direction wiring 82. An interlayer insulating layer (not shown)
10 is provided between the m conductors of X-direction wiring 82 and the n conductors of Y-direction wiring 83 to electrically separate these conductors (each of m and n is a positive integer).

[0172]

15 The interlayer insulating layer (not shown) is, for example, a SiO_2 layer formed by sputtering or the like and having a thickness of about 0.8 μm . For example, the interlayer insulating film is formed in the desired shape over the whole or part of the surface
20 of the substrate 81 on which X-direction wiring 82 has been formed. Specifically, the thickness of the interlayer insulating film is determined so as to ensure withstanding against the potential difference at the intersections of the conductors of X-direction
25 wiring 82 and Y-direction wiring 83. The conductors of

X-direction wiring 82 and Y-direction wiring 83 are respectively extended outward as external terminals.

[0173]

Pairs of electrodes (not shown) constituting
5 electron-emitting devices 84 are electrically connected to the m conductors of X-direction wiring 82 and the n conductors of Y-direction wiring 83 by connecting conductors 85 made of a conductive metal or the like.

[0174]

10 A scanning signal application means (not shown) for applying scanning signals for selecting the rows of electron-emitting devices 84 arranged in the X-direction is connected to X-direction wiring 82. On the other hand, a modulation signal generation means
15 for modulating voltages applied to the columns of electron-emitting devices 84 arranged in the Y-direction according to input signals is connected to Y-direction wiring 83. The drive voltage applied to each electron-emitting device is supplied as a voltage
20 corresponding to the difference between the scanning signal and the modulation signal applied to the element. In the present invention, Y-direction wiring 83 is connected to the gate electrodes 2 of the electron-emitting devices described above with respect
25 to the first example, while X-direction wiring is

connected to the cathodes 3 of the elements. This connection realizes a beam convergence effect which characterizes the present invention.

[0175]

5 In the above-described arrangement, each element can be selected by using the passive-matrix wiring to be driven independently.

[0176]

10 An image forming apparatus constructed by using an electron source having such a passive matrix array will be described with reference to Fig. 9. Fig. 9 is a diagram showing the display panel of the image forming apparatus.

[0177]

15 Referring to Fig. 9, the electron source having the plurality of electron-emitting devices described above with reference to Fig. 8 is provided on an electron source substrate 81. The substrate 81 is fixed on a rear plate 91. A face plate 96 has a glass substrate 93, a phosphor film 94 provided as a light emitting member on the internal surface of the glass substrate 93, a metal back 95, etc. The rear plate 91 and the face plate 96 are connected to a supporting frame 92 by using frit glass or the like. An envelope
20 98 is formed by being seal-bonded by baking in a vacuum
25

at about a temperature of 450°C for 10 minutes. The
electron-emitting devices 84 correspond to the
electron-emitting regions shown in Fig. 9. X-direction
wiring 82 and Y-direction wiring 83 are connected to
5 the pairs of electrodes of the electron-emitting
elements in this example.

[0178]

The envelope 97, as described above, is
constituted by the face plate 96, the supporting frame
10 92, and the rear plate 91. A supporting member (not
shown) called a spacer is provided between the face
plate 96 and the rear plate 91 to enable the envelope
98 to have a sufficiently high strength for resisting
atmospheric pressure.

15 [0179]

After fabrication of the phosphor film, the metal
back 95 is made by smoothing the inner surface of the
phosphor film (ordinarily called "filming") and by
thereafter depositing Al by vacuum evaporation or the
20 like.

[0180]

The face plate 96 further has a transparent
electrode (not shown) provided on outer surface of the
phosphor film 94 to improve the conductivity of the
25 phosphor film 94.

[0181]

The scanning circuit 102 will be described. The scanning circuit 102 includes M switching devices (schematically shown as S1 to Sm in the figure). Each of the switching devices S1 to Sm selects one of the output voltage from a direct-current voltage source Vx and 0 (V) (ground level). The switching devices S1 to Sm are respectively connected to terminals Dx1 to Dxm of the display panel 101. Each of the switching devices S1 to Sm operates on the basis of a control signal Tscan output from a control circuit 103, and may be a combination of a switching device such as a field-effect transistor (FET) and other components.

[0182]

In this example, the direct-current voltage source Vx is configured to output a constant voltage such that the drive voltage to be applied to a device which is not scanned on the basis of characteristics of the electron-emitting device (electron emitting threshold value voltage), is not higher than the electron-emitting threshold value voltage.

[0183]

The control circuit 103 has the function of matching the operations of the components with each other to suitably perform display on the basis of input

signals externally supplied. The control circuit 103 generates control signals Tscan, Tsft, and Tmry to the components on the basis of sync signal Tsync supplied from a sync signal separation circuit 106.

5 [0184]

The sync signal separation circuit 106 is a circuit for separating sync signal components and luminance signal components from an NTSC television signal externally supplied. This circuit can be formed
10 by using an ordinary frequency separation (filter) circuit, etc. The sync signal separated by the sync signal separation circuit 106 is formed of a vertical sync signal and a horizontal sync signal. However, it is shown as Tsync in the figure for convenience sake.
15 Image luminance signal components separated from the television signal are shown as DATA signal for convenience sake. The DATA signal is input to a shift register 104.

[0185]

20 The shift register 104 is a device for serial to parallel conversion, with respect to each image line, of the DATA signal which is input in time sequence. The shift register 104 operates on the basis of control signal Tsft supplied from the control circuit 103.

25 (That is, control signal Tsft may be considered to be a

shift clock for the shift register.) Data
corresponding to one image line after serial to
parallel conversion (corresponding to data for driving
N electron-emitting devices) is output as N parallel
5 signals Id1 to Idn from the shift register 104.

[0186]

The line memory 105 is a storage device for
storing data corresponding to one image line for a
necessary time period. The line memory 105 stores the
10 contents of the signals Id1 to Idn according to control
signal Tmry supplied from the control circuit 103. The
stored contents are output as I'd1 to I'dn to be input
to a modulation signal generator 107.

[0187]

15 The modulation signal generator 107 is a signal
source for suitably modulating signals for driving the
electron-emitting devices according to image data items
I'd1 to I'dn. Output signals from the modulation
signal generator 107 are applied to the electron-
20 emitting devices in the display panel 111 through
terminals Doy1 to Doyn.

[0188]

As described above, each electron-emitting device
to which the present invention can be applied has basic
25 characteristics described below with respect to

emission current I_e . That is, there is a definite threshold value voltage V_{th} with respect to emission of electrons. Emission of electrons is caused only when a voltage higher than V_{th} is applied. When a voltage
5 higher than the electron emission threshold value is applied to the electron-emitting device, the emission current changes according to changes in the applied voltage. Therefore, in a case where a voltage in the form of pulses is applied to the electron-emitting
10 device, electron emission is not caused when the value of the applied voltage is lower than the electron emission threshold value, but an electron beam is output when the value of the applied voltage is equal to or higher than the electron emission threshold
15 value. In this case, the strength of the electron beam can be controlled by changing the pulse crest value V_m . Also, the total amount of charge of the output electron beam can be controlled by changing the pulse width P_w .
[0189]

20 Therefore, a voltage modulation method, a pulse-width modulation method or the like can be used as a method for modulating the electron-emitting device according to the input signal. If the voltage modulation method is carried out, a voltage modulation
25 type of circuit capable of generating voltage pulses

having a constant duration, and modulating the pulse crest value according to input data may be used as modulation signal generator 107.

[0190]

5 If the pulse-width modulation method is carried out, a pulse-width modulation type of circuit capable of generating voltage pulses having a constant crest value and modulating the pulse width of the voltage pulses according to input data may be used as
10 modulation signal generator 107.

[0191]

Each of the shift register 104 and the line memory 105 used in this example is of a digital signal type.

15 [0192]

In this example, a digital to analog converter circuit, for example, is used in the modulation signal generator 107 and an amplifier circuit, etc., are added if necessary. For example, in the case where the
20 pulse-width modulation method is used, a combination of a high-speed oscillator, a counter for counting the number of waves output from the oscillator, and a comparator for comparing the output value of the counter and the output value of the above-described
25 memory is used in the modulation signal generator 107.

[0193]

The configuration of the image forming apparatus described above is an example of the image forming apparatus to which the present invention can be applied. Various modifications and changes can be made therein on the basis of the technical spirit of the present invention. The input signal is not limited to the above-mentioned NTSC signal. Those in accordance with the PAL system and the SECAM system and other TV signals corresponding to a larger number of scanning lines (e.g., those for the MUSE system and other high-definition TV systems) may also be used.

[0194]

Images were displayed on an image display apparatus made in accordance with this example. High-luminance high-definition images had been displayed on the image display apparatus with stability for a long period of time.

[0195]

20 [Effects of the Invention]

According to the present invention, as described above, the specific capacitance of an electron-emitting device can be reduced and the drive voltage can also be reduced. An electron source having improved efficiency and a smaller beam size can be realized by using such

an electron-emitting device.

[0196]

An image forming apparatus having high resolution, e.g., a color flat-screen television can be realized by using the electron-emitting device in accordance with the present invention.

[Brief Description of the Drawings]

[Fig. 1]

Fig. 1 is a diagrams showing an example of a basic electron-emitting device in accordance with the present invention.

[Fig. 2]

Fig. 2 is a diagram showing a second example of the present invention.

[Fig. 3]

Fig. 3 is a diagram showing a third example of the present invention.

[Fig. 4]

Fig. 4 is a diagram showing a fourth example of the present invention.

[Fig. 5]

Fig. 5 is a diagram showing fabrication steps in a first example of the present invention;

[Fig. 6]

Fig. 6 is a diagram showing an example of an

arrangement for operating the electron-emitting device of the present invention.

[Fig. 7]

Fig. 7 is a diagram showing an example of an
5 operating characteristic of the basic electron-emitting device of the present invention.

[Fig. 8]

Fig. 8 is a diagram showing an example of the configuration of a passive matrix circuit using a
10 plurality of electron sources in accordance with the present invention.

[Fig. 9]

Fig. 9 is a diagram showing an example of the construction of an image forming panel using the
15 electron source of the present invention.

[Fig. 10]

Fig. 10 is a diagram showing an example of a circuit for the image forming panel using the electron source of the present invention.

20 [Fig. 11]

Fig. 11 is a diagram schematically showing the structure of a carbon nanotube.

[Fig. 12]

Fig. 12 is a diagram schematically showing the
25 structure of a graphite nanofiber.

[Fig. 13]

Fig. 13 is a diagram showing a conventional vertical FE structure.

[Fig. 14]

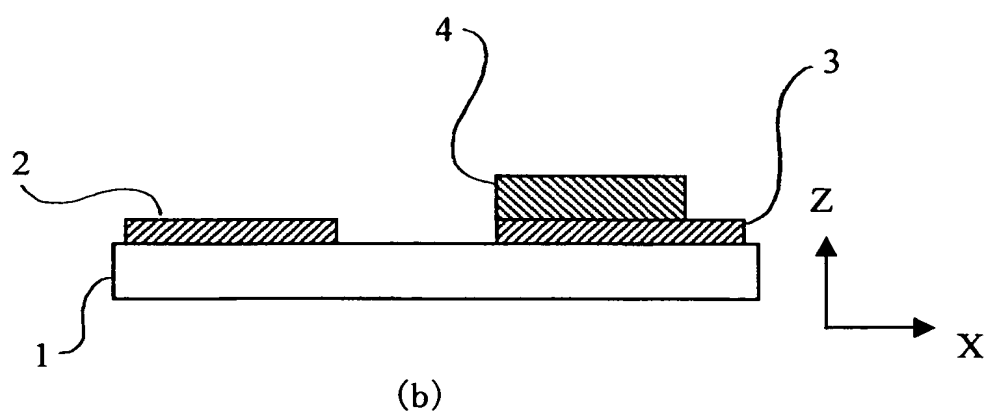
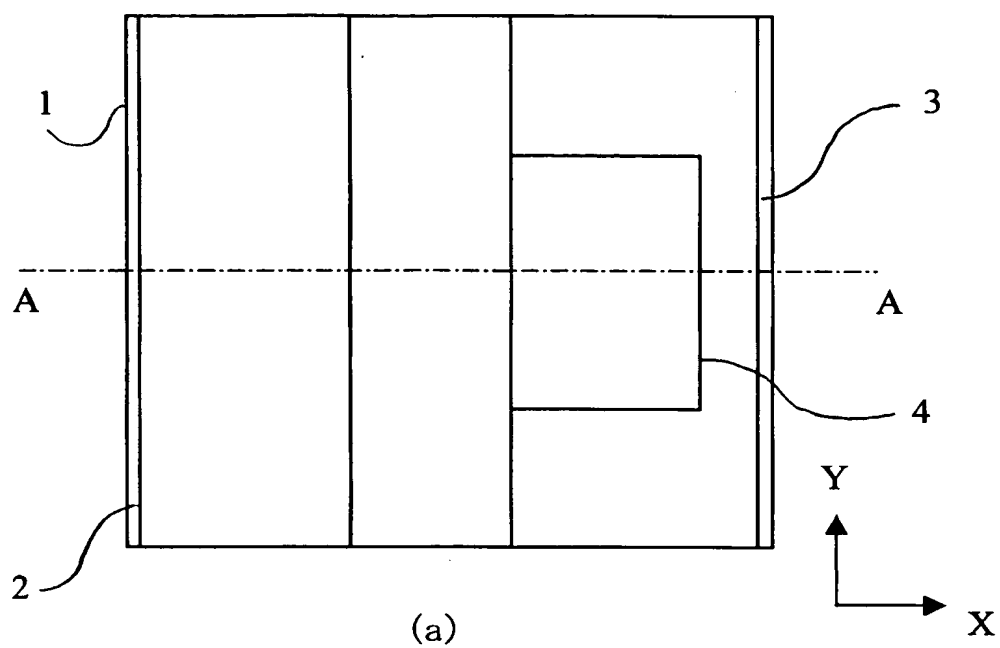
5 Fig. 14 is a diagram showing an example of a conventional lateral FE structure.

[Description of Reference Numerals or Symbols]

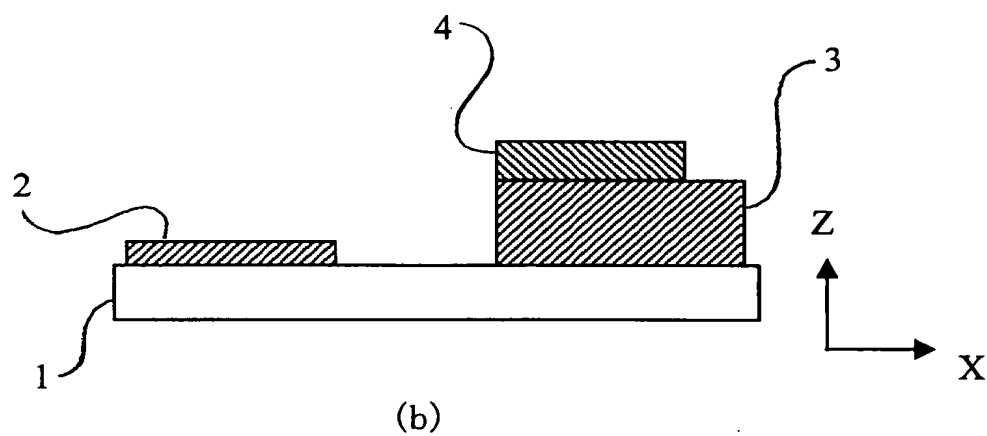
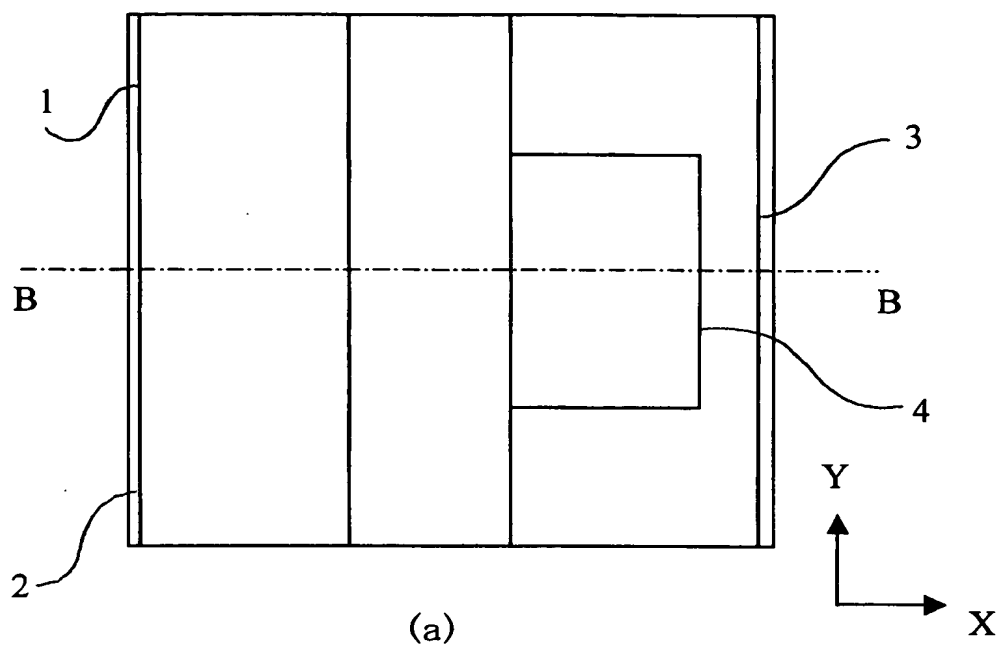
10 1 ... substrate
 2 ... gate electrode
 3 ... electrode
 4 ... electron-emitting material
 61 ... anode
 81 ... electron source substrate
 84 ... electron-emitting device

【書類名】 図面

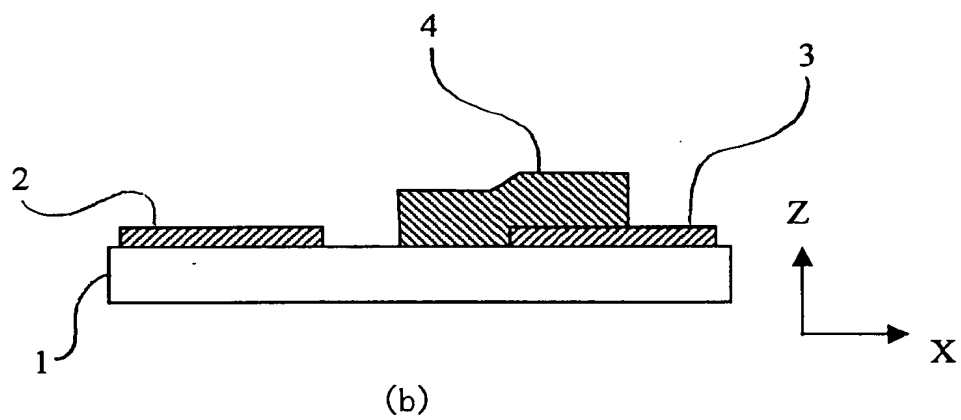
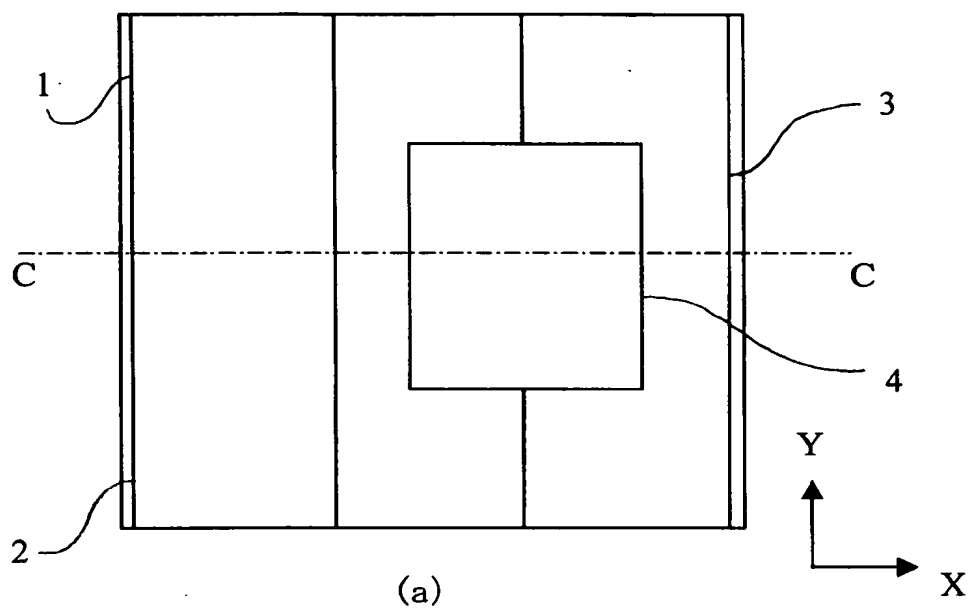
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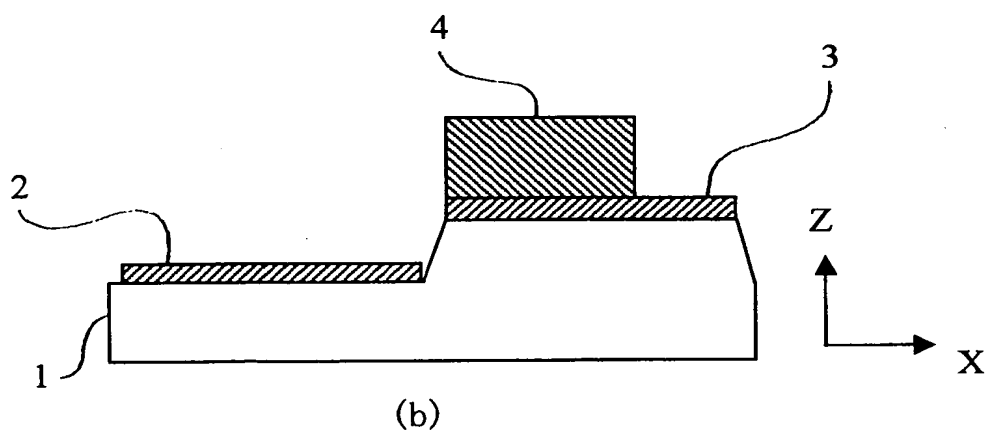
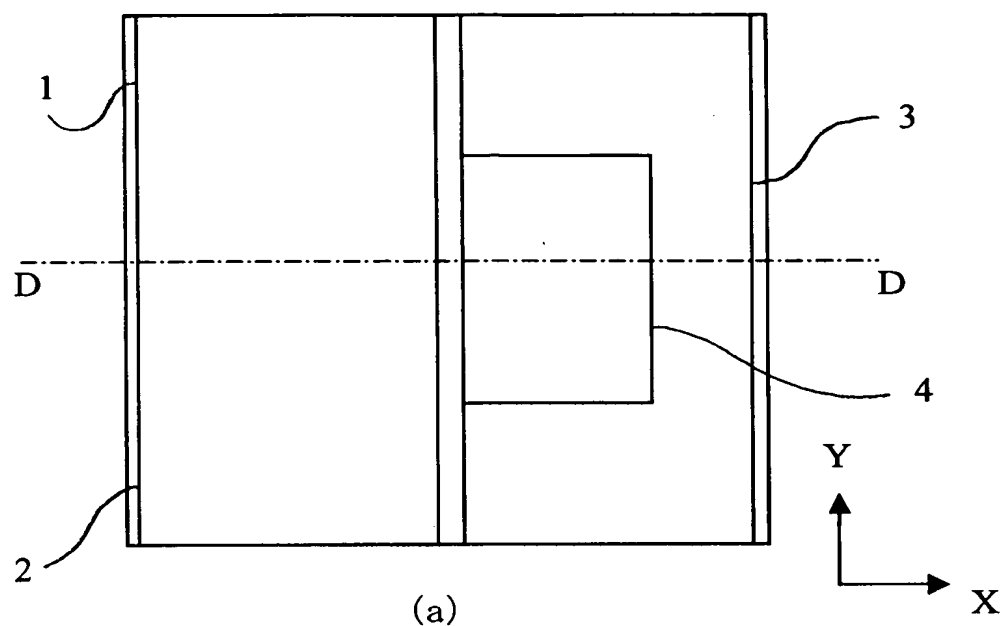
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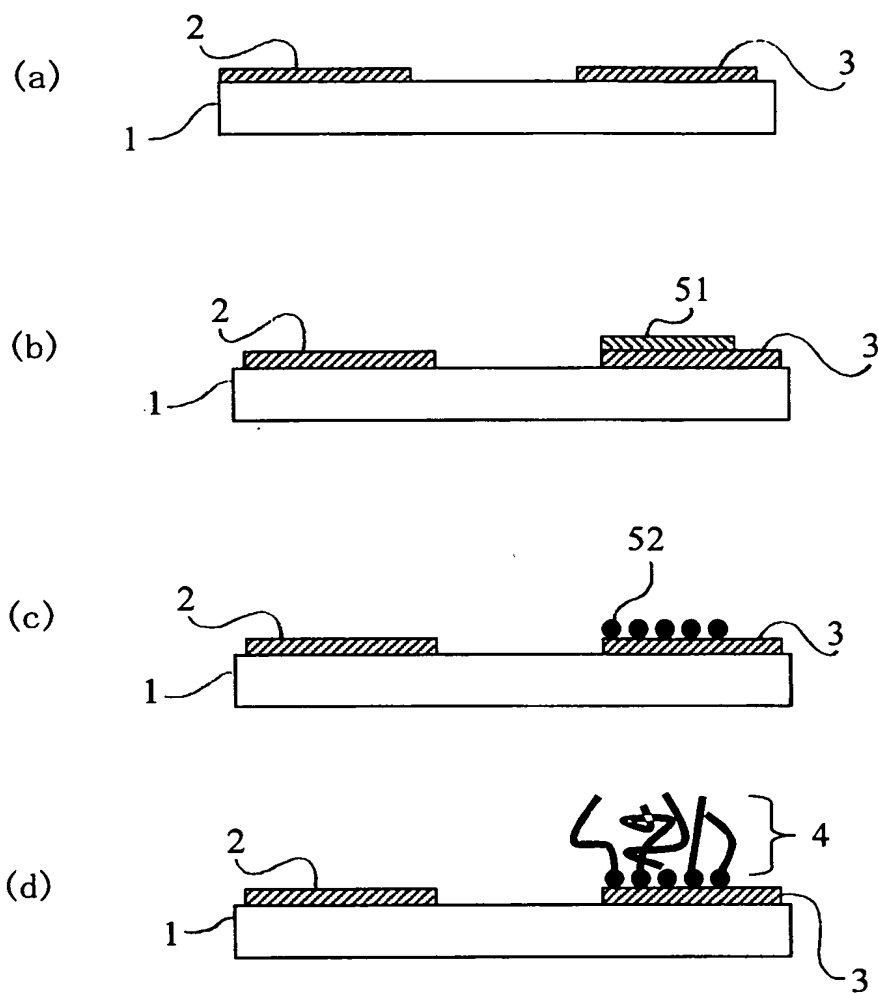
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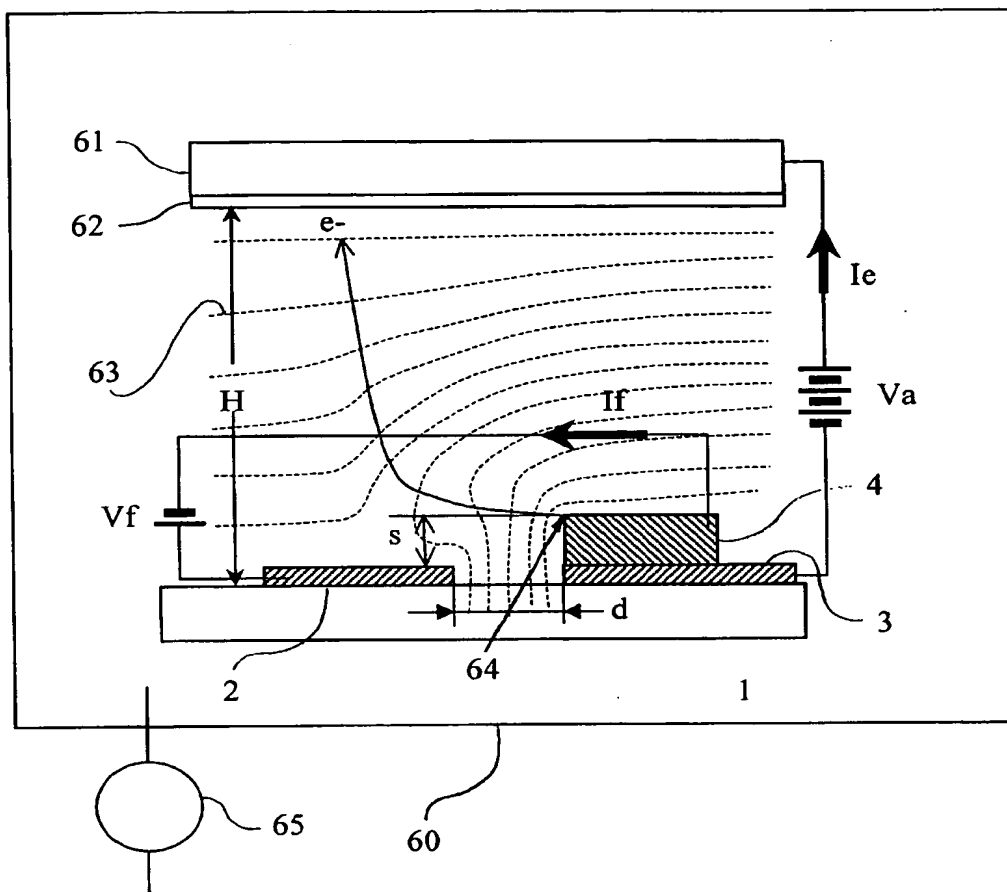
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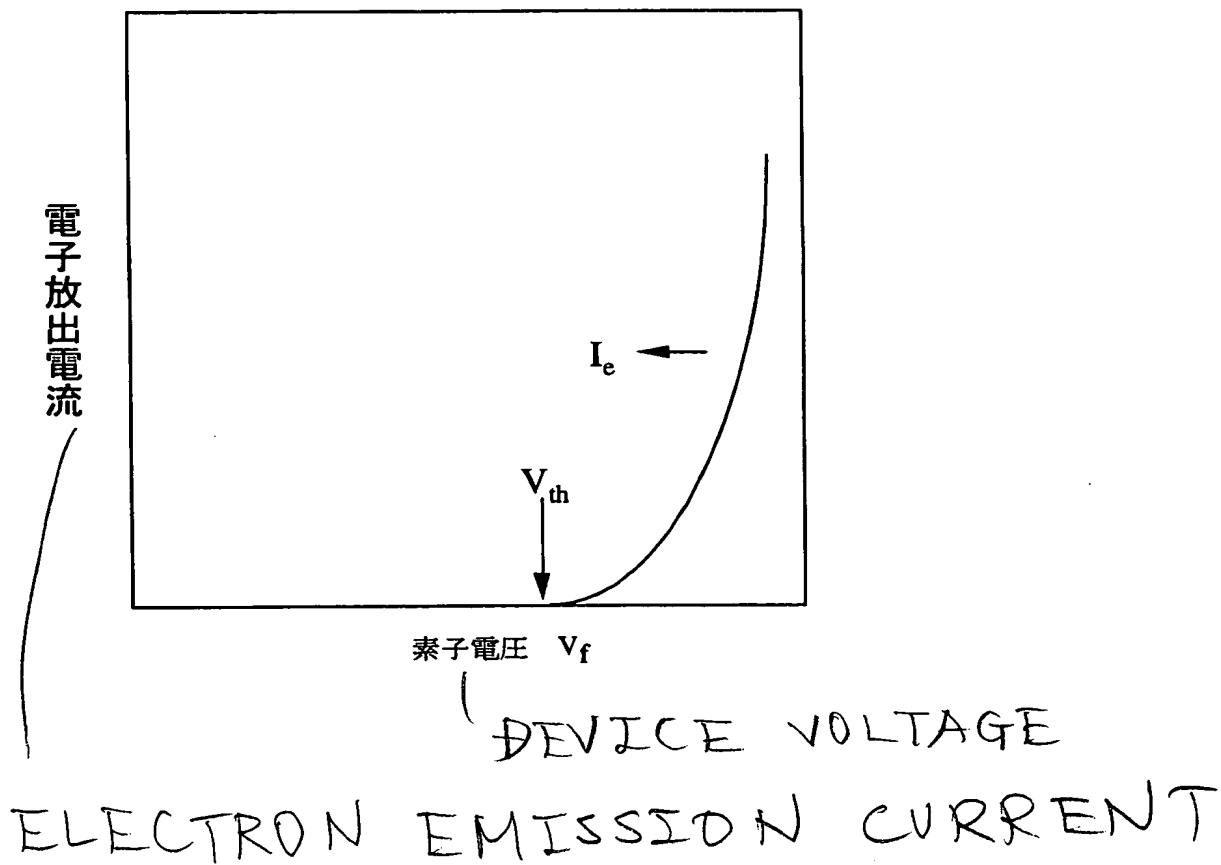
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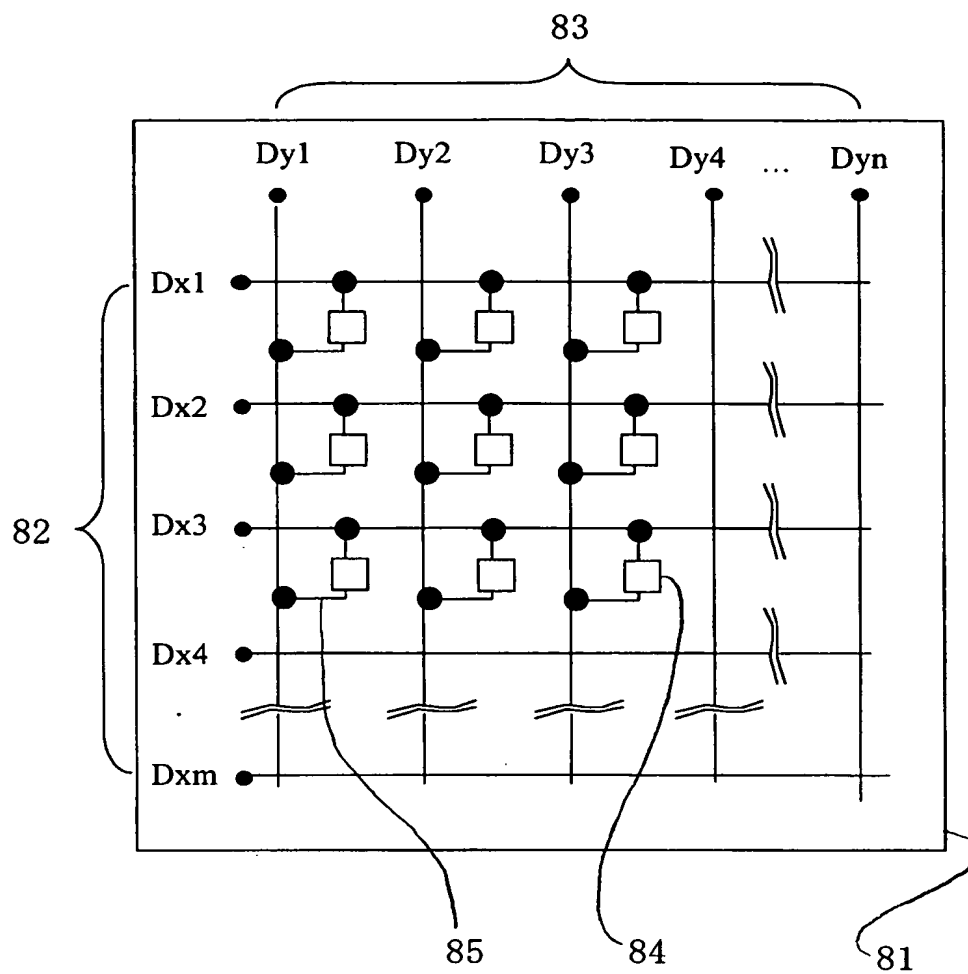
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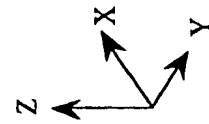
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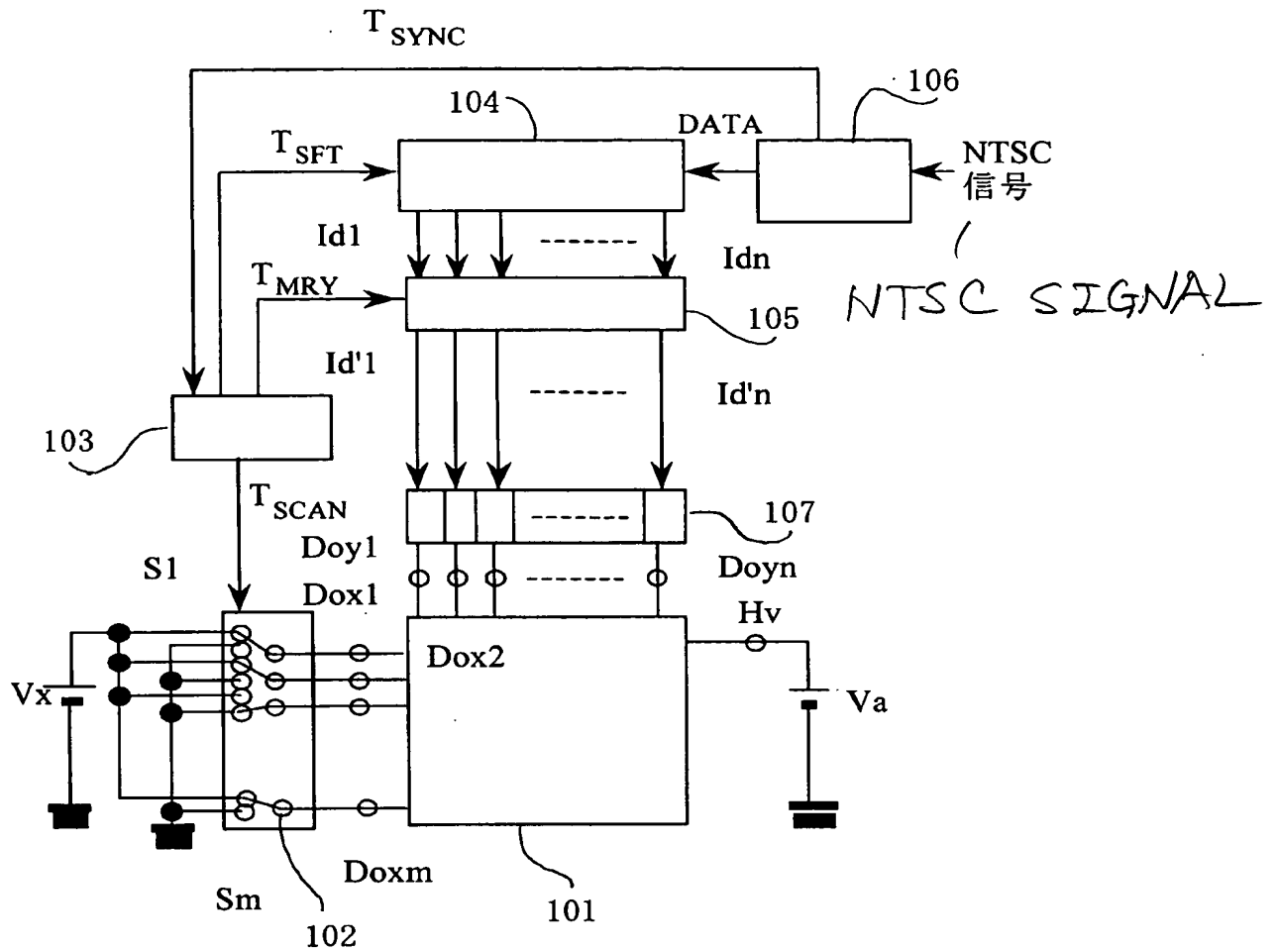
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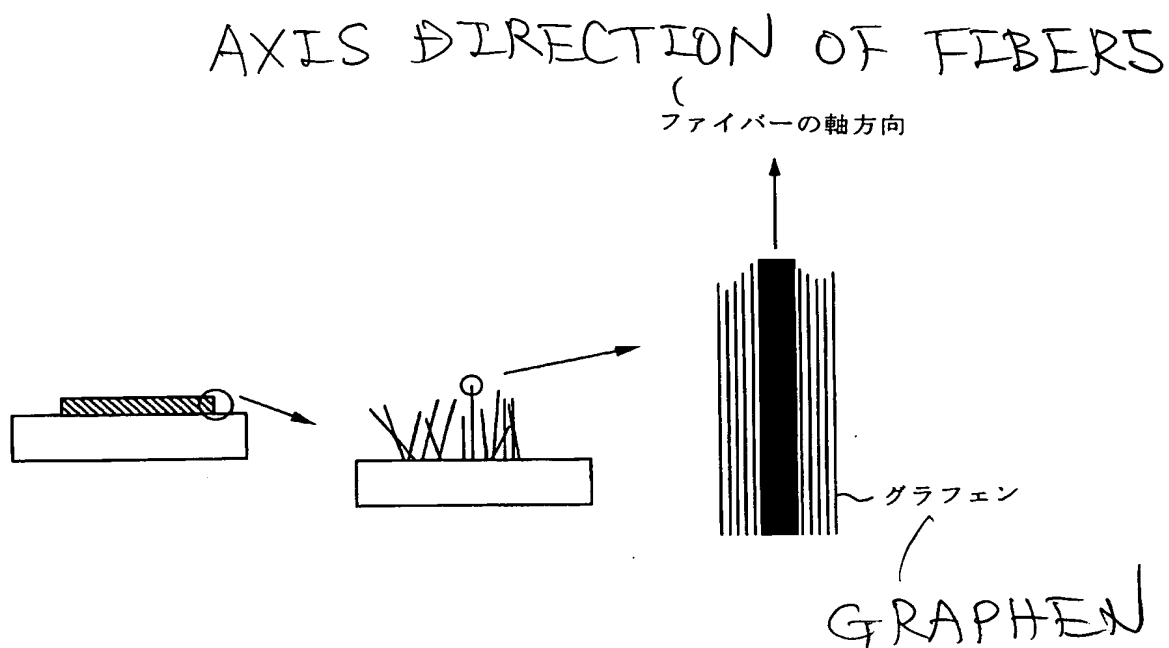
高压端子 Hv



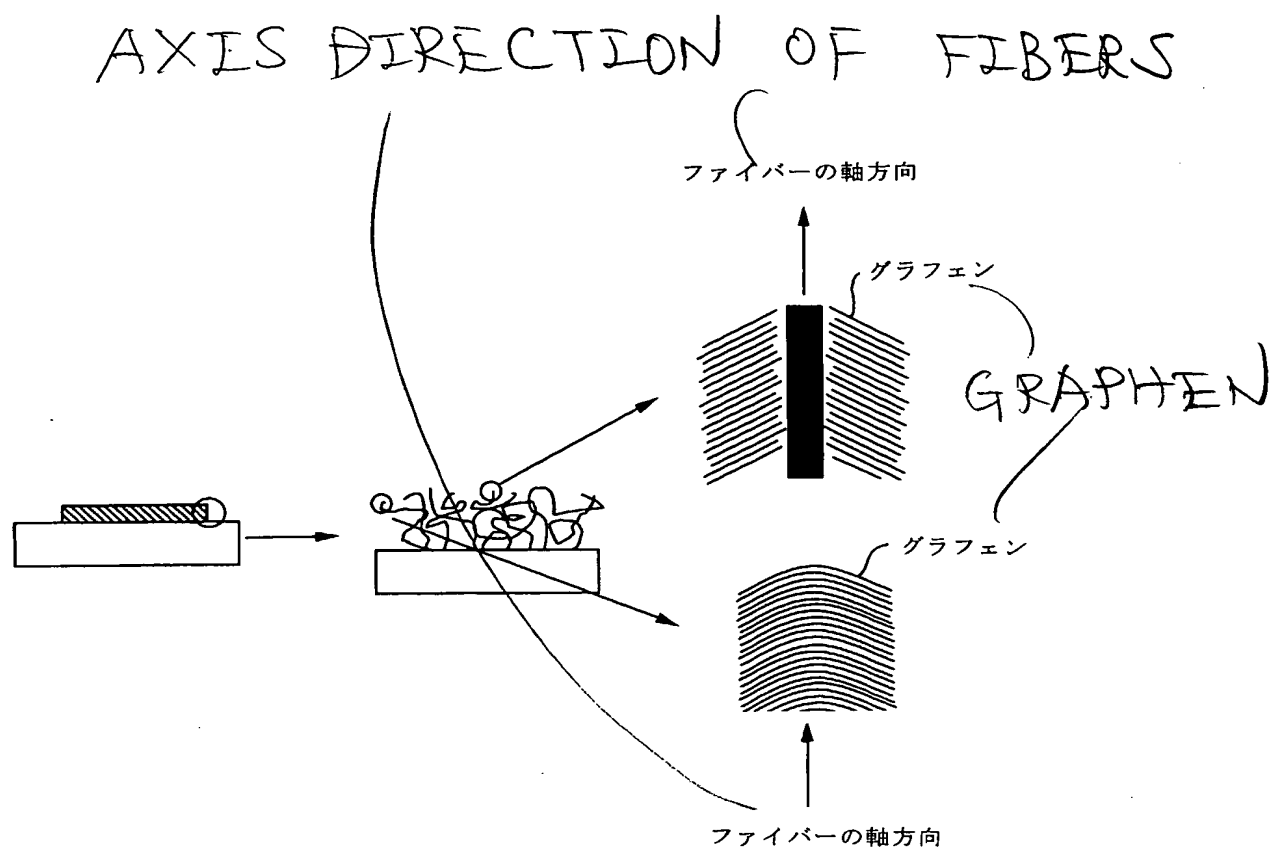
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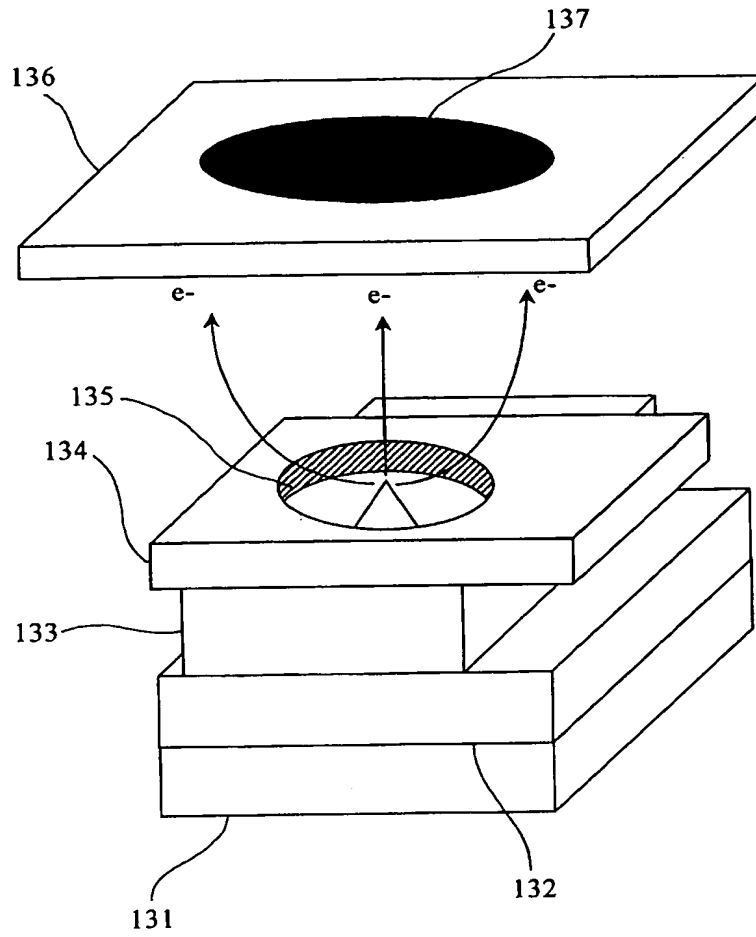
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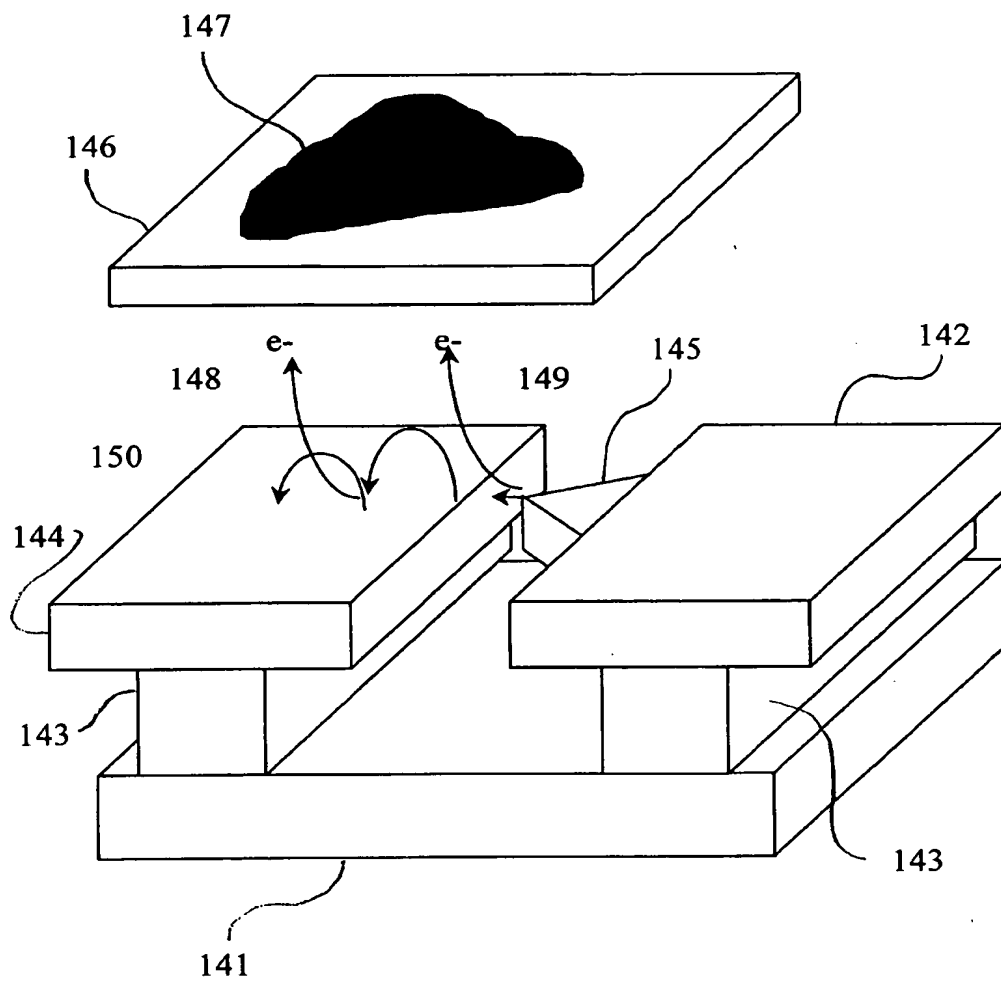
【図12】



【図 1 3】



【図14】



[Name of the Document] Abstract

[Abstract]

[Object]

An electron-emitting device in which the specific
5 capacitance and the drive voltage are reduced, and
which is capable of obtaining a finer electron beam by
controlling the trajectory of emitted electrons.

[Means for Achieving the Object]

An electron-emitting portion of an electron-
10 emitting member is positioned between the height of a
gate and the height of an anode. When the distance
between the gate and a cathode is d ; the potential
difference at driving the device is V_1 ; the distance
between the anode and the substrate is H ; and the
15 potential difference between the anode and the cathode
is V_2 , then the electric field $E_1 = V_1/d$ during driving
is configured to be within the range from 1 to 50 times
 $E_2 = V_2/H$.

[Selected Drawing]

20 Fig. 6

2001-255145

Applicant's Information

Identification No. [000001007]

1. Date of Change: August 30, 1990

(Reason for Change) New Registration

Address: 30-2, 3-chome, Shimomaruko, Ohta-ku, Tokyo

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Certificate No. 2001-3085916

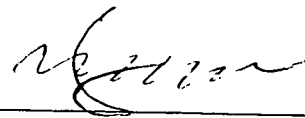
1711 / Translating

DECLARATION

I, NOBUAKI KATO, a Japanese Patent Attorney registered No.08517, of Okabe International Patent Office at No. 602, Fuji Bldg., 2-3, Marunouchi 3-chome, Chiyoda-ku, Tokyo, Japan, hereby declare that I have a thorough knowledge of Japanese and English languages, and that the attached pages contain a correct translation into English of the priority documents of Japanese Patent Application No. 2000-265819 filed on September 1, 2000 in the name of CANON KABUSHIKI KAISHA.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that wilful false statements and the like so made, are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such wilful false statements may jeopardize the validity of the application or any patent issuing thereon.

Signed this 19th day of August, 2003



NOBUAKI KATO

PATENT OFFICE
JAPANESE GOVERNMENT

This is to certify that the annexed is a true copy
of the following application as filed with this Office.

Date of Application: September 1, 2000

Application Number: Japanese Patent Application
No. 2000-265819

Applicant(s): CANON KABUSHIKI KAISHA

September 11, 2001

Commissioner: KOZO OIKAWA
Patent Office

(seal)

Certificate No. 2001-3083567

2000-265819

[Name of the Document]	Patent Application
[Reference No.]	4282009
[Date]	September 1, 2000
[Address to]	Commissioner of Patent Office KOZO OIKAWA
[International Classification]	H01J 1/30 H01J 31/12 H01J 9/00
[Title of the Invention]	ELECTRON-EMITTING DEVICE, ELECTRON-EMITTING APPARATUS, ELECTRON SOURCE, IMAGE-FORMING APPARATUS, AND MANUFACTURING METHOD OF ELECTRON-EMITTING DEVICE
[Number of Claims]	31
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[Patent Attorney]	
[Name]	JUNICHI WAKUTA

[Indication of Official Fee]

[Prepayment Ledger No.]	066073
[Amount]	21000

[List of Filed Materials]

[Material]	Specification	1
[Mateiral]	Drawing	1
[Material]	Abstract	1
[Proof Requirement]	Required	

[Name of the Document] Specification

[Title of the Invention] Electron-Emitting Device,
Electron-Emitting Apparatus, Electron Source, Image-
Forming Apparatus, And Manufacturing Method Of

5 Electron-Emitting Device

[What is claimed is]

 [Claim 1]

 An electron-emitting device forming
 a pair of electrodes;

10 first voltage application means for applying a
voltage between said pair of electrodes;

 a cathode connected to an electrode on a lower
electric potential side of said pair of electrodes
electrically, said cathode having an electron-emitting
15 member;

 an extraction electrode connected to an electrode
on a higher electric potential side of said pair of
electrodes electrically;

 an insulating substrate supporting said cathode
20 and said extraction electrode so as to be opposed to
each other with a gap between them;

 an anode arranged so as to be opposed to said
substrate in parallel with said substrate, said anode
receiving reached electrons emitted from said cathode;

25 second voltage application means for applying a

voltage between said anode and said cathode; and

an electron-emitting portion in said electron-emitting member at a height between a plane including said extraction electrode and a plane including said

5 anode, said device is characterized in that

when the distance of said gap is d ; an electric potential difference at a time when said first voltage application means drives said electron-emitting device is V_1 ; a distance between said anode and said substrate
10 is H ; and a potential difference between said anode and said cathode is V_2 , said potential difference generated by said second voltage application means, then an electric field at driving $E_1 = V_1/d$ is within a range from 1 to 50 times as large as an electric field $E_2 =$
15 V_2/H .

[Claim 2]

An electron-emitting device according to claim 1, wherein said electron-emitting member is formed on said cathode on said anode side, and a thickness of said
20 cathode is thicker than a thickness of said extraction electrode.

[Claim 3]

An electron-emitting device according to claim 1, wherein an end of said electron-emitting member on said
25 extraction electrode is formed to be located in said

gap.

[Claim 4]

An electron-emitting device according to claim 1,
wherein said electron-emitting member is formed on said
5 cathode on said anode side, and said substrate has a
difference in level between said extraction electrode
and said cathode, and further said cathode is
positioned to be closer to said anode than to said
extraction electrode with the difference in level
10 located between them.

[Claim 5]

An electron-emitting device according to any one
of claims 1-4, wherein said electron-emitting member is
made of a material containing carbon as a main
15 ingredient.

[Claim 6]

An electron-emitting device according to claim 5,
wherein said material containing carbon as a main
ingredient is an aggregate of fibrous carbon.

20 [Claim 7]

An electron-emitting device according to claim 6,
wherein said aggregate of fibrous carbon comprises a
graphite nanofiber, a carbon nanotube, amorphous
carbon, all grown up through catalyst particles, or a
25 mixture of these materials.

[Claim 8]

An electron-emitting device according to claim 7, wherein said catalyst particles are made of Pd, Ni, Fe, Co or an alloy of these substances.

5 [Claim 9]

An electron source characterized by at least a device row made by arranging a plurality of said electron-emitting devices according to any one of claims 1-8 in parallel to connect said arranged
10 electron-emitting device.

[Claim 10]

An electron source characterized by at least a device row made by arranging a plurality of said electron-emitting devices according to any one of
15 claims 1-8, and wiring to drive said devices is arranged in a matrix.

[Claim 11]

An image-forming apparatus characterized by said electron source according to claim 10, a fluorescent
20 substance as said anode, and a mechanism for controlling an electron quantity of each electron-emitting device by means of an information signal.

[Claim 12]

A manufacturing method of an electron-emitting
25 device, said method characterized by the steps of:

forming a pair of electrodes formed on an
insulating substrate with a gap between them;

forming metal oxide particles connected to either
of said pair of electrodes electrically;

5 performing reduction coagulation of said metal
oxide particles to be metal particles; and
growing fibrous carbon on said metal particles.

[Claim 13]

An electron-emitting device including a first
10 electrode and a second electrode disposed on a surface
of a substrate with a gap formed between said first
electrode and said second electrode; said device
forming an electric field substantially parallel to
said surface of said substrate by applying electric
15 potential higher than that of said first electrode to
said second electrode, said device emitting electrons,
said device characterized in that a plurality of
columnar substances containing carbon as a main
ingredient is arranged on said first electrode.

20 [Claim 14]

An electron-emitting device according to claim
13, wherein a material more effective in accelerating
deposition of the carbon than a material of said first
electrode is provided between said columnar substances
25 containing the carbon as the main ingredient and said

first electrode.

[Claim 15]

An electron-emitting device according to claim
14, wherein said material effective in accelerating the
5 deposition of the carbon is one comprising Pd, Ni, Fe,
Co or an alloy formed of said substances.

[Claim 16]

An electron-emitting device according to claim 14
or 15, wherein said material effective in accelerating
10 the deposition of the carbon is provided in a form of a
plurality of particles on said first electrode.

[Claim 17]

An electron-emitting device according to claim
16, wherein said plurality of particles are provided on
15 said first electrode at a density of 10^{10} particles/cm²
or higher.

[Claim 18]

An electron-emitting device according to any one
of claims 13-17, wherein a thickness of said first
20 electrode is thicker than the thickness of said second
electrode.

[Claim 19]

An electron-emitting device according to any one
of claims 13-18, wherein said columnar substances
25 containing the carbon as the main ingredient are ones

selected in a group of carbon nanotube and a graphite nanofiber.

[Claim 20]

An electron-emitting apparatus including an
5 electron-emitting device and a substantially plane-like anode electrode arranged to be opposed to said electron-emitting device, said apparatus characterized in that said electron-emitting device is one according to any one of claims 13-19.

10 [Claim 21]

An electron-emitting apparatus according to claim 20, wherein a distance between said anode electrode and a surface of said first electrode is shorter than a distance between said anode electrode and a surface of
15 said second electrode.

[Claim 22]

An electron-emitting apparatus according to claim 20, wherein distances between said anode electrode and ends of said columnar substances containing the carbon
20 as the main ingredient on a side at which said columnar substances are not connected to said first electrode are shorter than a distance between said anode electrode and the surface of said second electrode.

[Claim 23]

25 An electron-emitting apparatus comprising:

a first electrode including an electron-emitting member, and a second electrode for extracting electrons from said electron-emitting member;

first electric potential application means for
5 applying to said second electrode electric potential higher than electric potential applied to said first electrode;

a substrate including said first and said second electrodes on a surface of said substrate so as to
10 oppose said first and said second electrodes to each other with a gap;

an anode electrode including a surface parallel to the surface of said substrate substantially, said anode electrode disposed with a distance from said
15 substrate; and

second electric potential application means for applying to said anode electric potential higher than electric potential applied to said second electrode, said apparatus characterized in that

20 a plane containing a part of a surface of said electron-emitting member, said plane substantially parallel to the surface of said substrate, is positioned at a position between a plane containing a part of a surface of said extraction electrode, said
25 plane substantially parallel to the surface of said

substrate, and the surface of said anode electrode.

[Claim 24]

An electron-emitting apparatus according to claim
23, characterized in that when a distance between said
5 first electrode and said second electrode is d ; a
difference between the electric potential applied to
said first electrode and the electric potential applied
to said second electrode, both potential applied by
said first electric potential application means, is V_1 ;
10 the distance between the surface of said anode
electrode and the surface of said substrate is H ; and a
difference between the electric potential applied to
said anode by said second electric potential
application means and the electric potential applied to
15 said first electrode is V_2 , then an electric field $E_1 =$
 V_1/d is within the range from 1 to 50 times as large as
an electric field $E_2 = V_2/H$.

[Claim 25]

An electron-emitting apparatus according to claim
20 23 or 24, characterized in that said electron-emitting
member is made of a plurality of columnar substances
containing carbon as a main ingredient.

[Claim 26]

An electron-emitting apparatus according to claim
25 25, characterized in that a material more effective in

accelerating deposition of the carbon than the material of said first electrode is provided between said columnar substances containing the carbon as the main ingredient and said first electrode.

5 [Claim 27]

An electron-emitting apparatus according to claim 25, characterized in that said material effective in accelerating deposition of the carbon is one comprising Pd, Ni, Fe, Co or an alloy formed of said materials.

10 [Claim 28]

An electron-emitting apparatus according to claim 26 or 27, characterized in that said material effective in accelerating deposition of the carbon is provided in the form of a plurality of particles on said first
15 electrode.

[Claim 29]

An electron-emitting apparatus according to claim 28, characterized in that said plurality of particles is provided on said first electrode at a density of 10^{10}
20 particles/cm² or higher.

[Claim 30]

An electron-emitting apparatus according to any one of claims 23-29, characterized in that the thickness of said first electrode is thicker than the
25 thickness of said second electrode.

[Claim 31]

An electron-emitting apparatus according to any one of claims 23-30, characterized in that said columnar substances containing the carbon as the main
5 ingredient are ones selected in a group of carbon nanotube and a graphite nanofiber.

[Detailed Description of the Invention]

[0001]

[Field of the Industrial Application]

10 The present invention relates to an electron-emitting device, an electron-emitting apparatus, an electron source and an image-forming apparatus. The present invention can be used for a display apparatus such as a television broadcast display, a display for
15 use in a video conference system or a computer display, and for an image-forming apparatus designed as an optical printer using a photosensitive drum or the like.

[0002]

20 [Prior Art]

A field emission (FE) type of electron-emitting device which emits electrons from a surface of a metal when a strong electric field of 10^6 V/cm or higher is applied to the metal, and which is one of the known
25 cold cathode electron sources, is attracting attention.

[0003]

In recent years, especially in the field of the image-forming apparatus such as a display and the like, a flat-type display using liquid crystal has come into
5 wide use in place of a CRT. However, the flat-type display using the liquid crystal is not a selfluminous type display, and then has the problem of the necessity to have a back light, or the like. Consequently, a selfluminous type display has been desired.

10 [0004]

If the FE-type cold electron source is put to practical use, a thin emissive type image display apparatus can be realized. The FE-type cold electron source also contributes to reductions in power
15 consumption and weight of an image display apparatus.

[0005]

As an example of a vertical FE-type electron-emitting device, as shown in Fig. 13, one having an emitter 135 shaped in a circular cone or a quadrangular
20 pyramid in the substantially vertical direction from a substrate 131, for example, ones disclosed in C.A. Spindt, "Physical Properties of thin-film field emission cathodes with molybdenum cones", J. Appl. Phys., 47, 5248 (1976), and so forth (hereinafter, referred to as a "Spindt type"), has been known.
25

[0006]

As an example of a lateral FE structure, there is one composed of an emitter electrode having an acute extreme end, a gate electrode for drawing out electrons from the extreme end of the emitter, both formed to be parallel to a substrate, and a collector (called as an anode in the present application) configured in the direction crossing at right angles with the direction in which the gate electrode and the emitter electrode are opposed to each other (see USP 4,728,851, USP 4,904,895, IVMC91 Technical digest. P47, etc.).

[0007]

Also, Japanese Patent Application Laid-open No. 8-115652 discloses an electron-emitting device using fibrous carbon which is deposited in a narrow gap by performing thermal cracking of an organic chemical compound gas on a catalyst metal.

[0008]

[Problems to be solved by the Invention]

In an image display apparatus using one of the conventional FE-type electron sources, an electron beam spot is obtained which has a size (hereinafter referred to as "beam diameter") depending on the distance H between the electron source and the phosphor, the anode voltage V_a , and the device drive voltage V_f . The beam

diameter is smaller than a millimeter and the image display apparatus has sufficiently high resolution.

[0009]

In recent years, however, there has been a
5 tendency to require higher resolution of image display apparatuses.

[0010]

Further, with the increase in the number of display pixels, power consumption during driving due to
10 the device capacitance of electron-emitting devices is increased. Therefore there is a need to reduce the device capacitance and the drive voltage and to improve the efficiency of electron-emitting devices.

[0011]

15 In the above-described Spindt type of electron source, the gate is laminated on the substrate with the insulating layer interposed therebetween, so that parasitic capacitances are produced between large gate capacitances and a multiplicity of emitters. Moreover,
20 the drive voltage is high, several ten volts, and capacitive power consumption is disadvantageously large because of the specific structure.

[0012]

Also, since the beam of electrons drawn out
25 immediately spreads out, there is a need for a focusing

electrode for limiting spreading of the beam. For example, Japanese Patent Application Laid-open No. 7-6714 discloses a method of converging electron trajectories by disposing an electrode for focusing electrons. This method, however, has the problem of an increase in complexity of the manufacturing process, a reduction in electron emission efficiency, etc., due to the addition of the focusing electrode.

[0013]

10 In ordinary lateral FE electron sources, electrons emitted from the cathode are liable to impinge on the opposed gate electrode. Therefore the structure of lateral FE electron sources has the problem of a reduction in the efficiency (the ratio of the electron current flowing through the gate and the electron current reaching the anode) and considerable spreading of the beam shape on the anode.

[0014]

20 Moreover, for conversing the beam of a lateral FE type electron-emitting device, as disclosed in Japanese Patent Application Laid-open No. 09-063461, the structure in which a focusing electrode is arranged on the same plane as that of an electron-emitting unit, and the like were proposed. However, these structures have the problems of the complexity of their

25

manufacturing method, the increase of device areas, the decrease of the efficiency of electron emission, and the like.

[0015]

5 In the structure in which an emitter is formed at a position nearer to an anode than to a gate in the lateral FE structure, the ratio of electric field strengths of the electric field between the anode, at which electrons finally arrive, and the emitter to the
10 electric field between the emitter and the gate is not considered. Consequently, the structure becomes one in which emitted electrons spread.

[0016]

 In view of the above-described problems, an
15 object of the present invention is to provide an electron-emitting device in which the specific capacitance is reduced, which has a lower drive voltage, and which is capable of obtaining a finer electron beam by controlling the trajectory of emitted
20 electrons.

[0017]

[Means for solving the Problems]

 To achieve the above-described object, the present invention is an electron-emitting device
25 forming a pair of electrodes; first voltage application

means for applying a voltage between the pair of electrodes; a cathode connected to an electrode on a lower electric potential side of the pair of electrodes electrically, the cathode having an electron-emitting member; an extraction electrode connected to an electrode on a higher electric potential side of the pair of electrodes electrically; an insulating substrate supporting the cathode and the extraction electrode so as to be opposed to each other with a gap between them; an anode arranged so as to be opposed to the substrate in parallel with the substrate, the anode receiving reached electrons emitted from the cathode; second voltage application means for applying a voltage between the anode and the cathode; and an electron-emitting portion in the electron-emitting member at a height between a plane including the extraction electrode and a plane including the anode, the device is characterized in that when the distance of the gap is d ; a potential difference at a time when the first voltage application means drives the electron-emitting device is V_1 ; a distance between the anode and the substrate is H ; and an electric potential difference between the anode and the cathode is V_2 , the potential difference generated by the second voltage application means, then an electric field at driving $E_1 = V_1/d$ is

within a range from 1 to 50 times as large as an
electric field $E^2 = V^2/H$.

[0018]

In the above-described arrangement, the place at
5 which the electric field concentrates is limited to one
side of the region where an emitter material is formed,
thereby enabling emitted electrons to be first drawn
out toward the extraction electrode and then made to
reach the anode with no possibility of impinging on the
10 extraction electrode. As a result, the electron
emission efficiency is improved. Also, there is no
possibility of scattering of electrons on the
extraction electrode, so that the size of the beam spot
obtained on the anode is smaller than that of the
15 conventional beam spot of the beam scattering on the
extraction electrode.

[0019]

Hereupon, each of the pair of electrodes may be
formed to be integrated with either the cathode or the
20 extraction electrode. Alternatively, the each of the
pair of electrodes may be formed as an independent
member.

[0020]

Moreover, it was found that, by setting the
25 strength of the electric field between the cathode and

the extraction electrode to be the same degree as that of the electric field between the cathode and the anode, the drawn out electrons could reach the anode without impinging on the extraction electrode.

5 [0021]

Moreover, it is suitable that the electron-emitting member is formed on the cathode on the anode side, and that a thickness of the cathode is thicker than a thickness of the extraction electrode.

10 [0022]

An end of the electron-emitting member on the extraction electrode may be formed to be located in the gap.

[0023]

15 Moreover, the electron-emitting device may be configured in order that the electron-emitting member may be formed on the cathode on the anode side, and that the substrate may have a difference in level between the extraction electrode and the cathode, and
20 further that the cathode may be positioned to be closer to the anode than to the extraction electrode with the difference in level located between them.

[0024]

Moreover, it is suitable that the electron-
25 emitting member is made of a material containing carbon

as a main ingredient.

[0025]

Moreover, it is suitable that the material
containing carbon as a main ingredient is an aggregate
5 of fibrous carbon.

[0026]

By using the fibrous carbon as the material of
the electron-emitting member, it was made to be
possible to take out electrons in a very low electric
10 field.

[0027]

Moreover, it is suitable that the aggregate of
the fibrous carbon comprises a graphite nanofiber, a
carbon nanotube, amorphous carbon, all grown up through
15 catalyst particles, or a mixture of these materials.

[0028]

Moreover, it is suitable that the catalyst
particles are made of Pd, Ni, Fe, Co or an alloy of
these substances.

20 [0029]

Moreover, the present invention is an electron
source characterized by at least a device row made by
arranging a plurality of the electron-emitting devices
in parallel to connect the arranged electron-emitting
25 device.

[0030]

Moreover, the present invention is an electron source characterized by at least a device row made by arranging a plurality of the electron-emitting devices, and wiring to drive the devices is arranged in a matrix.

[0031]

Moreover, the present invention is an image-forming apparatus characterized by the electron source, a fluorescent substance as the anode, and a mechanism for controlling an electron quantity of each electron-emitting device by means of an information signal.

[0032]

Moreover, the present invention is a manufacturing method of an electron-emitting device, the method characterized by the steps of: forming a pair of electrodes formed on an insulating substrate with a gap between them; forming metal oxide particles connected to either of the pair of electrodes electrically; performing reduction coagulation of the metal oxide particles to be metal particles; and growing fibrous carbon on the metal particles.

[0033]

Moreover, the present invention is an electron-emitting device including a first electrode and a

second electrode disposed on a surface of a substrate with a gap formed between the first electrode and the second electrode; the device forming an electric field substantially parallel to the surface of the substrate by applying electric potential higher than that of the first electrode to the second electrode, the device emitting electrons, the device characterized in that a plurality of columnar substances containing carbon as a main ingredient is arranged on the first electrode.

10 [0034]

Moreover, a material more effective in accelerating deposition of the carbon than a material of the first electrode may be provided between the columnar substances containing the carbon as the main ingredient and the first electrode.

15 [0035]

Moreover, the material effective in accelerating the deposition of the carbon is one comprising Pd, Ni, Fe, Co or an alloy formed of the substances.

20 [0036]

Moreover, the material effective in accelerating the deposition of the carbon is provided in a form of a plurality of particles on the first electrode.

[0037]

25 Moreover, the plurality of particles may be

provided on the first electrode at a density of 10^{10} particles/cm² or higher.

[0038]

Moreover, it is suitable that a thickness of the
5 first electrode is thicker than the thickness of the second electrode.

[0039]

Moreover, it is suitable that the columnar substances containing the carbon as the main ingredient
10 are ones selected in a group of carbon nanotube and a graphite nanofiber.

[0040]

Moreover, the present invention is an electron-emitting apparatus including an electron-emitting
15 device and a substantially plane-like anode electrode arranged to be opposed to the electron-emitting device, the apparatus characterized in that the electron-emitting device is the one described above.

[0041]

20 Moreover, it is suitable that a distance between the anode electrode and a surface of the first electrode is shorter than a distance between the anode electrode and a surface of the second electrode.

[0042]

25 Moreover, it is suitable that distances between

the anode electrode and ends of the columnar substances containing the carbon as the main ingredient on a side at which the columnar substances are not connected to the first electrode are shorter than a distance between
5 the anode electrode and the surface of the second electrode.

[0043]

Moreover, the present invention is an electron-emitting apparatus comprising: a first electrode
10 including an electron-emitting member, and a second electrode for extracting electrons from the electron-emitting member; first electric potential application means for applying to the second electrode electric potential higher than electric potential applied to the
15 first electrode; a substrate including the first and the second electrodes on a surface of the substrate so as to oppose the first and the second electrodes to each other with a gap; an anode electrode including a surface parallel to the surface of the substrate
20 substantially, the anode electrode disposed with a distance from the substrate; and second electric potential application means for applying to the anode electric potential higher than electric potential applied to the second electrode, the apparatus
25 characterized in that a plane containing a part of a

surface of the electron-emitting member, the plane substantially parallel to the surface of the substrate, is positioned at a position between a plane containing a part of a surface of the extraction electrode, the
5 plane substantially parallel to the surface of the substrate, and the surface of the anode electrode.
[0044]

Moreover, it is suitable that, when a distance between the first electrode and the second electrode is
10 d ; a difference between the electric potential applied to the first electrode and the electric potential applied to the second electrode, both potential applied by the first electric potential application means, is V_1 ; the distance between the surface of the anode
15 electrode and the surface of the substrate is H ; and a difference between the electric potential applied to the anode by the second electric potential application means and the electric potential applied to the first electrode is V_2 , then an electric field $E_1 = V_1/d$ is
20 within the range from 1 to 50 times as large as an electric field $E_2 = V_2/H$.

[0045]

Moreover, the electron-emitting member may be made of a plurality of columnar substances containing
25 carbon as a main ingredient.

[0046]

Moreover, a material more effective in accelerating deposition of the carbon than the material of the first electrode may be provided between the columnar substances containing the carbon as the main ingredient and the first electrode.

[0047]

Moreover, the material effective in accelerating deposition of the carbon may be one comprising Pd, Ni, Fe, Co or an alloy formed of the materials.

[0048]

Moreover, the material effective in accelerating deposition of the carbon may be provided in the form of a plurality of particles on the first electrode.

[0049]

Moreover, the plurality of particles may be provided on the first electrode at a density of 10^{10} particles/cm² or higher.

[0050]

Moreover, it is suitable that the thickness of the first electrode is thicker than the thickness of the second electrode.

[0051]

Moreover, it is suitable that the columnar substances containing the carbon as the main ingredient

are ones selected in a group of carbon nanotube and a graphite nanofiber.

[0052]

[Embodiments of the Invention]

5 Preferred embodiments of the present invention will be described in detail with reference to the accompanying drawings. The description of components of the embodiments made below with respect to the size, material and shape of the components and the relative
10 positions of the components is not intended to limit the scope of the present invention except for particular mention of specified details.

[0053]

The operating voltage V_f of FE devices is
15 generally determined by the electric field at an extreme end of an emitter obtained from the Poisson equation and by the current density of electron emission current according to the relational expression called "Fowler-Nordheim equation" with a work function
20 of the electric field and the emitter portion used as a parameter.

[0054]

A stronger electric field is obtained as the electric field necessary for emission of electrons as
25 the distance D between the emitter extreme end and the

gate electrode is smaller or the radius r of the emitter extreme end is smaller.

[0055]

On the other hand, the maximum size X_d in the X-
5 direction of the electron beam obtained on the anode (e.g., the maximum reach from the center of the circular beam shape 137 shown in Fig. 13) is expressed in such a form as to be proportional to (V_f/V_a) in simple calculation.

10 [0056]

As is apparent from this relationship, an increase in V_f results in an increase in beam diameter.

[0057]

Consequently, there is a need to minimize the
15 distance D and the radius of curvature r in order to reduce V_f .

[0058]

Beam shapes in conventional arrangements will be described with reference to Figs. 13 and 14. In Figs.
20 13 and 14, substrates which are corresponding components of the two arrangements are indicated by 131 and 141; emitter electrodes by 132 and 142; insulating layers by 133 and 143.

[0059]

25 In the case of the Spindt type described above

with reference to Fig. 13, when V_f is applied between the emitter 135 and the gate 134, the strength of the electric field at the extreme end of the projection of the emitter 135 is increased and electrons are thereby
5 taken out of a conical emitter portion about the extreme end into the vacuum.

[0060]

The electric field at the extreme end of the emitter is formed based on the shape of the extreme end
10 of the emitter to have a certain finite area on the same, so that electrons are perpendicularly drawn out from the finite emitter extreme end area according to the potential.

[0061]

15 Simultaneously, other electrons are emitted at various angles. Electrons emitted at larger angles are necessarily drawn toward the gate.

[0062]

As a result, if the gate is formed so as to have
20 a circular opening, the distribution of electrons on the anode 136 shown in Fig. 13 forms a substantially circular beam shape 137. That is, the shape of the beam obtained is closely related to the shape of the drawing gate and to the distance between the gate and
25 the emitter.

[0063]

As the prior art in which electrons are drawn out along one direction, there is a lateral FE structure as shown in Fig. 14.

5 [0064]

In Fig. 14, 141 is a substrate. 142 is an emitter electrode. 143 is an insulator layer. 144 is a gate. 145 is an emitter. Incidentally, an anode 146 is disposed on a substrate opposed to the substrate 141 on which the emitter 145 and the gate 144 are mounted.

[0065]

In the arrangement shown in Fig. 14, a very strong electric field (a lateral electric field) which is substantially parallel to the surface of the substrate 141 is generated between the emitter 145 and the gate 144. As a result, among the electrons emitted from the emitter 145, a part 149 of them is taken out in the vacuum, and the other electrons are taken in by the gate electrode 144.

20 [0066]

In the arrangement shown in Fig. 14, electric field vectors toward the anode 146 differ in direction from those causing emission of electrons (the electric field from the emitter 145 toward the gate 144). Therefore the distribution of electrons (beam spot)

formed by emitted electrons on the anode 146 is increased.

[0067]

The electric field of electrons drawn out
5 (referred to as "lateral electric field" in the
following description for convenience sake while the
electric field strengthening effect of the emitter
configuration is ignored) and the electric field toward
the anode (referred to as "vertical electric field" in
10 the following description) will further be described.

[0068]

As described above, electrons emitted from the
emitter are first drawn out by the lateral electric
field, fly toward the gate, and are then moved upward
15 by the vertical electric field to reach the anode.

[0069]

Important factors of this effect are the ratio of
the strengths of the lateral and vertical electric
fields and the relative position of the electron
20 emission point.

[0070]

When the lateral electric field is stronger than
the vertical electric field by an order of magnitude,
the trajectories of almost all of electrons drawn out
25 from the emitter are gradually bent by radial potential

produced by the lateral electric field so that the electrons fly toward the gate. A part of the electrons impinging on the gate ejects again in a scattering manner. After ejection, however, the electrons repeat
5 scattering while spreading out along the gate by forming elliptical trajectories again and again and while being reduced in number when ejecting until they are caught by the vertical electric field. Only after the scattered electrons have exceeded an equipotential
10 line formed by the gate potential (which line may be called "stagnation point"), they are moved upward by the vertical electric field.
[0071]

When the lateral electric field and the vertical
15 electric field are approximately equal in strength, the restraint imposed by the lateral electric field on electrons drawn out is reduced, although the trajectories of the electrons are bent by the radial potential. In this case, therefore, electron
20 trajectories appear along which electrons travel to be caught by the vertical electric field without impinging on the gate.
[0072]

It has been found that if the electron emission
25 position at which electrons are emitted from the

emitter is shifted from the gate plane toward the anode plane (see Fig. 6), emitted electrons can form trajectories such as to be caught by the vertical electric field with no possibility of impinging on the gate when the lateral electric field and the vertical electric field are approximately equal in strength, that is, the ratio of the strength of the lateral electric field to that of the vertical electric field is 1 to 1.

10 [0073]

Also, a study made of the electric field ratio has shown that if the distance between the gate electrode 144 and the extreme end of the emitter electrode 145 is d ; the potential difference (between the gate electrode and the emitter electrode) when the device is driven is V_1 ; the distance between the anode and the substrate (element) is H ; and the potential difference between the anode and the cathode (emitter electrode) is V_2 , a trajectory along which electrons drawn out impinge on the gate is formed when the lateral electric field $E_1 = V_1/d$ is 50 times or more stronger than the vertical electric field $E_2 = V_2/H$.

[0074]

The inventor of the present invention has also found that a height s (defined as the distance between

25

a plane containing a portion of a gate electrode 2 surface and substantially parallel to a substrate 1 surface and a plane containing an electron-emitting member 4 surface and substantially parallel to the substrate 1 surface (see Fig. 6)) can be determined such that substantially no scattering occurs on the gate electrode 2. The height s depends on the ratio of the vertical electric field and the lateral electric field (vertical electric field strength/lateral electric field strength). As the vertical-lateral electric field ratio is lower, the height s is lower. AS the lateral electric field is stronger, the necessary height s is higher.

[0075]

15 The height set in a practical manufacturing process ranges from 10 nm to 10 μm .

[0076]

In the conventional arrangement, the gate and the emitter are formed flush with each other along a common plane and the lateral electric field is stronger than the vertical electric field by an order of magnitude, so that there is a considerable tendency to reduce, by impingement on the gate, the amount of electrons drawn out into the vacuum.

25 [0077]

Further, in the conventional arrangement, the thickness and the width of the gate electrode, and relative positions of the gate, the emitter and the anode are determined so as to increase the strength of the electric field in the lateral direction, so that the electron distribution on the anode spreads widely.
[0078]

As described above, to restrict the distribution of electrons reaching the anode, it is necessary (1) to reduce V_f , (2) to unidirectionally draw out electrons, (3) to consider the trajectory of electrons and, if scattering on the gate occurs, (4) to consider the electron scattering mechanism (elastic scattering in particular).

[0079]

The arrangement of the present invention was zealously examined on the basis of the thought described above with the aim of providing an electron-emitting device in which the distribution of electrons is made finer, and in which the efficiency is improved.
[0080]

The electron-emitting device in accordance with the present invention described above will now be described below in detail by means of the preferred embodiments.

[0081]

Fig. 1(a) is a schematic plan view showing an example of an electron-emitting device in accordance with the present invention. Fig. 1(b) is a cross-sectional view taken along the line A-A of Fig. 1(a). Fig. 6 is schematic view of an arrangement in a state where the electron-emitting apparatus of the present invention is driven.

[0082]

10 In Figs. 1 and 6 are illustrated an insulating substrate 1, an extraction electrode 2 (also referred to as "gate electrode" or "second electrode"), a cathode electrode 3 (also referred to as "first electrode"), a cathode (emitter) material 4 provided on the cathode 3 (also referred to as "electron-emitting member").

In the device of the present invention, on the basis of the knowledge described above, if as shown in Fig. 6 the distance by which the emitter electrode (cathode electrode) 3 and the gate electrode (extraction electrode) 2 are spaced apart from each other is d ; the potential difference (the voltage between the emitter electrode 3 and the gate electrode 2) when the electron-emitting device is driven is V_f ; 25 the distance between the anode 61 and the surface of

the substrate 1 on which the electron-emitting device is arranged is H ; and the potential difference between the anode electrode 61 and the emitter electrode 3 is V_a , an electric field produced to drive the device: E_1
5 $= V_f/d$ is set within the range from 1 to 50 times as large as $E_2 = V_a/H$, both inclusive. The proportion of electrons impinging on the gate electrode 2 in electrons emitted from the emitter electrode side is reduced thereby. In this manner, a high-efficiency
10 electron-emitting device capable of preventing an emitted electron beam from spreading out widely can be obtained.
[0083]

Further, in the electron-emitting device of the
15 present invention, the electron-emitting member 4 is placed at a height s (defined as the distance between the plane containing a portion of the surface of gate electrode 2 and substantially parallel to the surface of substrate 1 and the plane containing the surface of
20 electron-emitting member 4 and substantially parallel to the surface of substrate 1 (see Fig. 6)) such that no scattering occurs on the gate electrode 2. The height s depends on the ratio of the vertical electric field and the lateral electric field (vertical electric
25 field strength/lateral electric field strength). As

the vertical-lateral electric field ratio is lower, the height s is lower. As the lateral electric field is stronger, the necessary height s is higher.

Practically, the height is not less than 10 nm not more
5 than 10 μm .

[0084]

Examples of the insulating substrate 1 are the following substrates whose surfaces are sufficiently cleansed: quartz glass; glass in which the content of
10 an impurity such as Na is reduced by partial substitution by K, for example; a laminate formed in such a manner that SiO_2 is laminated by sputtering or the like on soda lime glass, a silicon substrate or the like; and an insulating substrate made of a ceramic
15 such as alumina.

[0085]

Each of the extraction electrode 2 and cathode 3 is an electrically conductive member formed on the surface of the substrate 1 by an ordinary vacuum film
20 forming technique, such as evaporation or sputtering, or a photolithography technique so as to face each other. The material of the electrodes 2 and 3 is selected from, for example, carbon, metals, nitrides of metals, carbides of metals, borides of metals,
25 semiconductors, and metallic compounds of

semiconductors. The thickness of the electrodes 2 and 3 is set within the range from several ten nanometers to several ten microns. Preferably, the material of the electrodes 2 and 3 is a heat resistant material
5 formed of carbon, a metal, a nitride of a metal or a carbide of a metal.

[0086]

In particular, in the case of growth of fibrous carbon described below, the electrodes are preferably
10 formed of silicon having conductivity, e.g., doped polysilicon or the like.

[0087]

If there is apprehension about, for example, a voltage drop due to the small thickness of the
15 electrodes, or if a plurality of the electron-emitting devices are used in matrix form, a low-resistance wiring metallic material may be used to form suitable wiring portions on condition that it does not affect emission of electrons.

20 [0088]

The emitter material (electron-emitting member) 4 may be formed in such a manner that a film deposited by an ordinary vacuum film forming method such as sputtering is worked into the shape of the emitter by
25 using a technique such as reactive ion etching (RIE).

Alternatively, it may be formed by growing needle
crystals or whiskers by seed growth in chemical vapor
deposition (CVD). In the case of RIE, the control of
the emitter shape depends on the kind of the substrate
5 used, the kind of gas, the gas pressure (flow rate),
the etching time, the energy for forming plasma, etc.
In a CVD forming process, the emitter shape is
controlled by selecting the kind of the substrate, the
kind of gas, the flow rate, the growth temperature,
10 etc.

[0089]

Examples of the material used to form the emitter
(electron-emitting member) 4 are carbides, such as TiC,
ZrC, HfC, TaC, SiC, and WC, amorphous carbon, graphite,
15 diamondlike carbon, carbon containing dispersed
diamond, and carbon compounds. According to the
present invention, fibrous carbon is particularly
preferably used as the material of the emitter
(electron-emitting member) 4. "Fibrous carbon"
20 referred to in the description of the present invention
can also be expressed as "material in columnar form
containing carbon as a main constituent" or "material
in filament form containing carbon as a main
constituent". Further, "fibrous carbon" can also be
25 expressed as "fibers containing carbon as a main

constituent". More specifically, "fibrous carbon" in accordance with the present invention comprises carbon nanotubes, graphite nanofibers, and amorphous carbon fibers.

5 [0090]

The gap between the extraction electrode 2 and the cathode 3 and the drive voltage may be determined so that the value of the lateral electric field necessary for emission of electrons from the cathode material used is 1 to 50 times larger than that of the vertical electric field necessary for forming an image, as described above.

[0091]

In a case where a light-emitting member such as a phosphor is provided on the anode, the necessary vertical electric field is, preferably, within the 10^{-1} to 10 V/ μm range. For example, in a case where the gap between the anode and the cathode is 2 mm and 10 kV is applied between the anode and the cathode, the vertical electric field is 5 V/ μm . In this case, the emitter material (electron-emitting member) 4 to be used has an electron-emitting electric field value of 5 V/ μm or higher. The gap and the drive voltage may be determined in correspondence with the selected electron-emitting electric field value.

[0092]

An example of a material having an electric field threshold of several V/ μm is fibrous carbon, which is produced by cracking carbon hydride gas by the use of a catalyst (a material which promotes the deposition of carbon) (see Figs. 11 and 12). Each of Figs. 11 and 12 shows an example of the configuration of fibrous carbon. In each of Figs. 11 and 12, the configuration is schematically shown at the optical microscope level (to 1,000 times) in the left-hand section, at the scanning electron microscope level (to 30,000 times) in the middle section, and at the transmission electron microscope level (to 1,000,000 times) in the right-hand section.

15 [0093]

A graphene structure formed into a cylinder is called a carbon nanotube (a multilayer cylindrical graphene structure is called a multiwall nanotube). Its threshold value is minimized when the tube end is opened.

[0094]

The fibrous carbon shown in Fig. 12 may be produced at a comparatively low temperature by the use of a catalyst like a carbon nanotube. Fibrous carbon having such a configuration is composed of a graphene

25

layered body (thus, it may be referred to as "graphite nanofiber", and has an amorphous structure whose ratio is increased with temperature).

[0095]

5 The carbon nanotube and the graphite nanofiber are different from each other in the kinds of catalysts and in the temperatures of cracking. There are the case where the material having both the structures of the carbon nanotube and the graphite nanofiber can be
10 selected by the use of the same catalyst according to a temperature, and the case where only either of the two structures can be obtained.

[0096]

Each type of fibrous carbon has an electron
15 emission threshold value of about 1 to 10 V/ μm and is therefore preferred as the material of the emitter (electron-emitting member) 4 in accordance with the present invention.

[0097]

20 Fe, Co or the like is used for forming the carbon nanotube as the catalyst material. However, Pd or Ni can be used as a seed for forming carbon.

[0098]

In particular, if Pd or Ni is used, graphite
25 nanofibers can be formed at a low temperature (not

lower than 400°C). The necessary carbon nanotube forming temperature in the case of using Fe or Co is 800°C or higher. Also, the process of producing a graphite nanofiber material by using Pd or Ni, which
5 can be performed at a lower temperature, is preferred from the viewpoint of reducing the influence on other components and limiting the manufacturing cost.

[0099]

Further, the characteristic of Pd that resides in
10 enabling oxides to be reduced by hydrogen at a low temperature (room temperature) may be utilized. That is, palladium oxide may be used as a seed forming material.

[0100]

15 If hydrogen reduction using palladium oxide is performed, an initial agglomeration seed can be formed at a comparatively low temperature (equal to or lower than 200°C) without metallic film thermal agglomeration or ultrafine particle forming/deposition conventionally
20 used as ordinary seed forming techniques.

[0101]

The above-mentioned hydrocarbon gas may be, for example, acetylene, ethylene, methane, propane, or propylene. Further, CO or CO₂ gas or vapor of an
25 organic solvent such as ethanol or acetone may be used

in some case.

[0102]

As shown in FIG. 1, the electron-emitting point in the emitter (electron-emitting member) 4 is conjectured to exist at the position nearest to the gate, but the region where the emitter (electron-emitting member) exists will be referred to as "emitter region" regardless of contribution to emission of electrons.

10 [0103]

The position of the electron emission point (electron-emitting portion) in the "emitter region" and the electron-emitting operation will be described with reference to Figs. 6 and 7.

15 [0104]

The present device having a gap (the distance between the cathode electrode 3 and the extraction electrode 2) of several microns was set in a vacuum apparatus 60 such as shown in Fig. 6. A sufficiently high degree of vacuum about 10^{-4} Pa was produced by a evacuating pump 65. A high voltage V_a of several kilovolts was applied from a high voltage source ("second voltage application means" ("second potential application means")) to the anode 61, which was placed so that the surface of the anode (anode electrode) 61

20

25

is at the height H , which was several millimeters, from the surface of the substrate 1, as shown in Fig. 6.

The substrate 1 and the anode 61 were positioned relative to each other so that their surfaces are
5 parallel to each other.

[0105]

Between the cathode 3 and the extraction electrode 2 of the electron-emitting device, a pulse voltage of about several ten volts was applied as drive
10 voltage V_f from a power supply (not shown) ("first voltage application means" ("first potential application means")). Flowing device current I_f and electron emission current I_e were measured.

[0106]

15 It is supposed that, during this operation, equipotential lines 63 are formed as shown in Fig. 6 (an electric field (the direction of an electric field) substantially parallel to the surface of the substrate 1, and that the concentration of the electric field is
20 maximized at the point on a portion of the electron-emitting member 4 closest to the anode and facing the gap, as indicated by 64. It is thought that electrons are emitted mainly from the portion of the electron-emitting material in the vicinity of this electric
25 field concentration point, where the concentration of

the electric field is maximized. An I_e characteristic such as shown in Fig. 7 was obtained. That is, I_e rises abruptly at a voltage about half the applied voltage. The I_f characteristic (not shown) was similar
5 to the I_e characteristic but the value of I_f was sufficiently smaller than that of I_e .

[0107]

In the following, on the basis of this principle, an image-forming apparatus obtained by arranging a
10 plurality of the electron-emitting devices to which the present invention can be applied will be described with reference to Fig. 8. In Fig. 8 are illustrated an electron source substrate 81, X-direction wiring 82, Y-direction wiring 83, electron-emitting device 84 in
15 accordance with the present invention, and a connecting conductor 85.

[0108]

X-direction wiring 82 has m conductors $DX1$, $DX2$, ... DXm , which may be constituted by, for example,
20 a conductive metal formed by vacuum evaporation, printing, sputtering, or the like. The material, film thickness, and width of the wiring are selected according to a suitable design. Y-direction wiring 83 has n conductors $DY1$, $DY2$, ... DYn and is formed in the
25 same manner as X-direction wiring 82. An interlayer

insulating layer (not shown) is provided between the m
conductors of X-direction wiring 82 and the
n conductors of Y-direction wiring 83 to electrically
separate these conductors (each of m and n is a
5 positive integer).

[0109]

The interlayer insulating layer (not shown) is,
for example, a SiO₂ layer formed by vacuum evaporation,
printing, sputtering, or the like. For example, the
10 interlayer insulating film is formed in the desired
shape over the whole or part of the surface of the
substrate 81 on which X-direction wiring 82 has been
formed and the film thickness, material and fabrication
method are selected to ensure withstanding against the
15 potential difference at the intersections of the
conductors of X-direction wiring 82 and Y-direction
wiring 83 in particular. The conductors of X-direction
wiring 82 and Y-direction wiring 83 are respectively
extended outward as external terminals.

20 [0110]

Pairs of electrodes (not shown) constituting
electron-emitting devices 84 are electrically connected
to the m conductors of X-direction wiring 82 and the n
conductors of Y-direction wiring 83 by connecting
25 conductors 85 made of a conductive metal or the like.

[0111]

The materials forming wiring 82 and wiring 83, the material forming the connecting conductors 85 and the materials forming the pairs of device electrodes
5 may be entirely constituted of common constituent elements or partially constituted of common constituent elements, or may be constituted of different constituent elements. These materials are selected from, for example, the above-described device electrode
10 materials. If the materials of the device electrodes and the wiring materials are the same, the wiring conductors connected to the device electrodes can be considered to be device electrodes.

[0112]

15 A scanning signal application means (not shown) for applying scanning signals for selecting the rows of electron-emitting devices 84 arranged in the X-direction is connected to X-direction wiring 82. On the other hand, a modulation signal generation means
20 for modulating voltages applied to the columns of electron-emitting devices 84 arranged in the Y-direction according to input signals is connected to Y-direction wiring 83. The drive voltage applied to each electron-emitting device is supplied as a voltage
25 corresponding to the difference between the scanning

signal and the modulation signal applied to the element.

[0113]

In the above-described arrangement, each device
5 can be selected by using the passive-matrix wiring to be driven independently.

[0114]

An image forming apparatus constructed by using an electron source having such a passive matrix array
10 will be described with reference to Fig. 9. Fig. 9 schematically shows an example of the display panel of the image forming apparatus. Referring to Fig. 9, a plurality of electron-emitting devices is disposed on an electron source substrate 81, which is fixed on a
15 rear plate 91. A face plate 96 has a glass substrate 93, a phosphor film 94 provided as a light emitting member on the internal surface of the glass substrate 93, a metal back (anode) 95, etc. The rear plate 91 and the face plate 96 are connected to a supporting
20 frame 92 by using frit glass or the like. An envelope 97 is formed by being seal-bonded by baking in, for example, atmospheric air, a vacuum or in nitrogen in the 400 to 500°C temperature range for 10 minutes or longer.

25 [0115]

The envelope 97, as described above, is constituted by the face plate 96, the supporting frame 92, and the rear plate 91. The rear plate 91 is provided mainly for the purpose of reinforcing the substrate 81. If the substrate 81 itself has sufficiently high strength, there is no need to separately provide the rear plate 91. That is, the supporting frame 92 may be directly seal-bonded to the substrate 81 and the envelope 97 may be formed by the frame plate 96, the supporting frame 92 and the substrate 81. A supporting member (not shown) called a spacer may be provided between the face plate 96 and the rear plate 91 to enable the envelope 97 to have a sufficiently high strength for resisting atmospheric pressure.

[0116]

[Examples]

Examples of the present invention will be described below in detail.

[0117]

(Example 1)

Fig. 1(a) shows a top view of an electron-emitting device fabricated in this embodiment. Fig. 1(b) is a cross-sectional view taken along the line A-A of Fig. 1(a).

[0118]

Fig. 1 illustrates an insulating substrate 1, an extraction electrode 2 (gate), a cathode 3, and a cathode (emitter) material 4.

5 [0119]

The process of fabricating the electron-emitting device of this embodiment will be described in detail.
(Step 1)

A quartz substrate was used as substrate 1.
10 After sufficiently cleansing the substrate, a 5 nm thick Ti film (not shown) and a 30 nm thick poly-Si film (arsenic doped) were successively deposited by sputtering on the substrate as gate electrode 2 and cathode (emitter) electrode 3.

15 [0120]

Next, a resist pattern was formed by photolithography using a positive photoresist (AZ1500/ from Clariant Corporation).

[0121]

20 Thereafter, dry etching was performed on the poly-Si (arsenic doped) layer and Ti layer with the patterned photoresist used as a mask, CF₄ gas being used to etch the Ti layer. An extraction electrode 2 and a cathode 3 having a gap of 5 μm therebetween were
25 thereby formed (Fig. 5(a)).

[0122]

(Step 2)

Next, a Cr having a thickness of about 100 nm was deposited on the entire substrate by electron beam (EB) evaporation.

[0123]

A resist pattern was formed by photolithography using a positive photoresist (AZ1500/ from Clariant Corporation).

10 [0124]

An opening corresponding to a region (100 μm square) where electron-emitting material was to be provided was formed on the cathode 3 with the patterned photoresist used as a mask. Cr at the opening was removed by using a cerium nitrate etching solution.

[0125]

After removing the resist, a complex solution prepared by adding isopropyl alcohol, etc., to a Pd complex was applied to the entire substrate by spin coating.

[0126]

After application of the solution, a heat treatment was performed in atmospheric air at 300°C to form a palladium oxide layer 51 having a thickness of about 10 nm. Thereafter, Cr was removed by using a

cerium nitrate etching solution (Fig. 5(b)).

[0127]

(Step 3)

The substrate was baked at 200°C, atmospheric air
5 was evacuated, and a heat treatment was then performed
in 2% hydrogen flow diluted with nitrogen. At this
stage, particles 52 having a diameter of about 3 to 10
nm were formed on the surface of the device. The
density of the particles at this stage was estimated at
10 about 10^{11} to 10^{12} particles/cm² (Fig. 5(c)).

[0128]

(Step 4)

Subsequently, a heat treatment was performed in a
0.1% ethylene flow diluted with nitrogen at 500°C for
15 10 minutes. The state after the heat treatment was
observed with a scanning electron microscope to find
that a multiplicity of fibrous carbon having a diameter
of about 10 to 25 nm and extending like fibers while
curving or bending had been formed in the Pd-coated
20 region. The thickness of the fibrous carbon layer was
about 500 nm (Fig. 5(d)).

[0129]

This electron-emitting device was set in the
vacuum apparatus 60 shown in Fig. 6. A sufficiently
25 high vacuum of about 2×10^{-5} Pa was produced by the

evacuating pump 62. Voltage $V_a = 10$ kV was applied as anode voltage to the anode 61 distanced by $H = 2$ mm from the device, as shown in Fig. 6. Also, a pulse voltage of $V_f = 20$ V was applied as drive voltage to the device. Device current I_f and electron emission current I_e thereby caused were measured.

[0130]

The I_f and I_e characteristics of the electron-emitting device were as shown in Fig. 7. That is, I_e rises abruptly at a voltage about half the applied voltage, and a current of about $1 \mu\text{A}$ was measured as electron emission current I_e at a V_f value of 15 V. On the other hand, the I_f characteristic was similar to the I_e characteristic but the value of I_f was smaller than that of I_e by an order of magnitude or more.

[0131]

The obtained beam had a generally rectangular shape having a longer side along the Y-direction and a shorter side in the X-direction. The beam width was measured with respect to different gaps of $1 \mu\text{m}$ and $5 \mu\text{m}$ while V_f was fixed at 15 V and the distance H to the anode was fixed at 2 mm. Table 1 shows the results of this measurement.

[0132]

25 Table 1

	Va = 5 kV	Va = 10 kV
Gap: 1 μm	60 μm in x-direction 170 μm in y-direction	30 μm in x-direction 150 μm in y-direction
Gap: 5 μm	93 μm in x-direction 170 μm in y-direction	72 μm in x-direction 150 μm in y-direction

[0133]

It was possible to change the necessary electric field for driving by changing the growth conditions.

In particular, the average particle size of Pd

5 particles formed by reduction of palladium oxide is related to the diameter of fibers thereafter grown. It was possible to control the average Pd particle size through the Pd density in the Pd complex coating and the rotational speed of spin coating.

10 [0134]

The fibrous carbon of this electron-emitting device was observed with the transmission electron microscope to recognize a structure in which graphenes are layered, as shown in the right-hand section of Fig.

15 12. The graphene stacking intervals (in the Z-axis direction) resulting from heating at a lower temperature, about 500°C were indefinite and was 0.4 nm. As the heating temperature was increased, the grating intervals became definite. The intervals
20 resulting from heating at 700°C were 0.34 nm, which is close to 0.335 nm in graphite.

[0135]

(Example 2)

Fig. 2 shows a second example of the present invention.

5 [0136]

In this example, an electron-emitting device was fabricated in the same manner as that in the first example except that the cathode 3 corresponding to that in the first embodiment had a thickness of 500 nm and
10 fibrous carbon provided as electron-emitting material had a thickness of 100 nm. Currents I_f and I_e in the fabricated electron-emitting device were measured.

[0137]

In this device arrangement, the electron emission
15 point was positively heightened (toward the anode) relative to the gate electrode by increasing the thickness of the cathode 3. Trajectories along which electrons impinge on the gate were thereby reduced, thereby preventing a reduction in efficiency and
20 occurrence of a beam-thickening phenomenon.

[0138]

Also in this device arrangement, the electron emission current I_e at $V_f = 20V$ was about $1 \mu A$. On the other hand, the I_f characteristic was similar to the I_e
25 characteristic but the value of I_f was smaller than

that of I_e by two orders of magnitude.

[0139]

The results of measurement of the beam diameter in this embodiment were substantially the same as those shown in Table 1.

[0140]

(Example 3)

Fig. 3 shows a third example of the present invention.

10 [0141]

The present example shows the case where, in the step corresponding to step 2 in the first example, palladium oxide 51 was provided over the gap and the electrode 3 at almost the midpoint in the gap (about a half of the distance of the gap). The present example is the same as the first example in the following steps 3 and 4.

[0142]

The electric field in the electron-emitting device of this example was twice as strong as that in the first example because the gap was reduced, thereby enabling the drive voltage to be reduced to about 8 V.

[0143]

(Example 4)

25 Fig. 4 shows a fourth example of the present

invention. In this example step 1 and step 2 described above with respect to the first embodiment were changed as described below.

[0144]

5 (Step 1)

A quartz substrate was used as substrate 1. After sufficiently cleansing the substrate, a 5 nm thick Ti film and a 30 nm thick poly-Si film (arsenic doped) were successively deposited by sputtering on the
10 substrate as cathode (emitter) electrode 3.

[0145]

Next, a resist pattern was formed by photolithography using a positive photoresist (AZ1500/ from Clariant Corporation).

15 [0146]

Next, dry etching was performed on the poly-Si layer and Ti layer by using CF_4 gas, with the patterned photoresist used as a mask. Cathode 3 was thereby formed.

20 [0147]

The quartz substrate was then etched to a depth of about 500 nm by using a mixed acid formed of hydrofluoric acid and ammonium fluoride.

[0148]

25 Subsequently, a 5 nm thick Ti film and a 30 nm

thick Pt film were successively deposited on the substrate as gate electrode 2 by again performing sputtering. After removing the photoresist from the cathode, a resist pattern was again formed by using a
5 positive photoresist (AZ1500/ from Clariant Corporation) to form the gate electrode.

[0149]

Next, dry etching was performed on the Pt layer and Ti layer by using Ar, with the patterned
10 photoresist used as a mask. Electrode 2 was thereby formed so that the step formed between the electrodes functions as a gap.

[0150]

Next, a resist pattern was formed on the cathode,
15 a Ni film having a thickness of about 5 nm was formed by resistance heating evaporation having a good straight-in effect, and oxidation was thereafter performed at 350°C for 30 minutes.

[0151]

20 This step was followed by the same steps as those in the first example.

[0152]

The above-described device arrangement enabled formation of a finer gap such that electrons were
25 effectively emitted at a lower voltage of about 6 V.

[0153]

Because the height of the electron-emitting material (film thickness) was thick, electrons were drawn out not only from the upper portion of the film but also from an intermediate portion. Thus, the arrangement in this embodiment has the effect of preventing a reduction in efficiency due to impingement of electrons on the gate electrode and occurrence of a beam-thickening phenomenon.

10 [0154]

(Example 5)

An image-forming apparatus obtained by arranging a plurality of the electron-emitting devices to which the present invention can be applied will be described with reference to Figs. 8, 9, and 10. In Fig. 8 are illustrated an electron source substrate 81, X-direction wiring 82, Y-direction wiring 83, electron-emitting devices 84 in accordance with the present invention, and connecting conductors 85.

20 [0155]

The matrix wiring shown in Fig. 8, in which the device capacitance is increased by arranging a plurality of electron-emitting devices, has a problem that, even when a short pulse produced by pulse-width modulation is applied, the waveform is dulled or

distorted by capacitive components to cause failure to obtain the necessary grayscale level, for example. In this example, therefore, a structure was adopted in which an interlayer insulating layer designated by 91 in FIG. 9 was provided by the immediate side of the electron-emitting region as shown in the first embodiment to limit the increase in capacitive components in regions other than the electron-emitting region.

10 [0156]

Referring to Fig. 8, X-direction wiring 82 has m conductors DX1, DX2, ... DXm, which has a thickness of about 1 μm and a width of 300 μm , and which is formed of an aluminum wiring material by evaporation. The material, film thickness, and width of the wiring conductors are selected according to a suitable design. Y-direction wiring 83 has n conductors DY1, DY2, ... DYn, which has a thickness of 5 μm and width of 100 μm , and which is formed in the same manner as X-direction wiring 82. An interlayer insulating layer (not shown) is provided between the m conductors of X-direction wiring 82 and the n conductors of Y-direction wiring 83 to electrically separate these conductors (each of m and n is a positive integer).

25 [0157]

The interlayer insulating layer (not shown) was, for example, a SiO₂ layer formed by sputtering or the like and having a thickness of about 0.8 μm. For example, the interlayer insulating film was formed in
5 the desired shape over the whole or part of the surface of the substrate 81 on which X-direction wiring 82 had been formed. Specifically, the thickness of the interlayer insulating film was determined so as to ensure withstanding against the potential difference at
10 the intersections of the conductors of X-direction wiring 82 and Y-direction wiring 83, and so that the device capacitance per device was 1 pF or less and the withstanding voltage was 30 V. The conductors of X-direction wiring 82 and Y-direction wiring 83 were
15 respectively extended outward as external terminals.
[0158]

Pairs of electrodes (not shown) constituting electron-emitting devices 84 are electrically connected to the m conductors of X-direction wiring 82 and the n
20 conductors of Y-direction wiring 83 by connecting conductors 85 made of a conductive metal or the like.
[0159]

A scanning signal application means (not shown) for applying scanning signals for selecting the rows of
25 electron-emitting devices 84 arranged in the X-

direction is connected to X-direction wiring 82. On the other hand, a modulation signal generation means for modulating voltages applied to the columns of electron-emitting devices 84 arranged in the Y-
5 direction according to input signals is connected to Y-direction wiring 83. The drive voltage applied to each electron-emitting device is supplied as a voltage corresponding to the difference between the scanning signal and the modulation signal applied to the
10 element. In the present invention, Y-direction wiring was connected to be high potential, while X-direction wiring was connected to be low potential. This connection realized a beam convergence effect which characterized the present invention.

15 [0160]

In the above-described arrangement, each element can be selected by using the passive-matrix wiring to be driven independently.

[0161]

20 An image forming apparatus constructed by using an electron source having such a passive matrix array will be described with reference to Fig. 9. Fig. 9 is a diagram showing the display panel of the image forming apparatus.

25 [0162]

Referring to Fig. 9, the electron source having the plurality of electron-emitting devices is provided on an electron source substrate 81. The substrate 81 is fixed on a rear plate 91. A face plate 96 has a
5 glass substrate 93, a phosphor film 94 provided as a light emitting member on the internal surface of the glass substrate 93, a metal back 95, etc. The rear plate 91 and the face plate 96 are connected to a supporting frame 92 by using frit glass or the like.
10 An envelope 98 is formed by being seal-bonded by baking in a vacuum at about a temperature of 450°C for 10 minutes. The electron-emitting devices 84 correspond to the electron-emitting regions shown in Fig. 9. X-direction wiring 82 and Y-direction wiring 83 are
15 connected to the pairs of electrodes of the electron-emitting elements in this embodiment.

[0163]

The envelope 97, as described above, is constituted by the face plate 96, the supporting frame
20 92, and the rear plate 91. A supporting member (not shown) called a spacer is provided between the face plate 96 and the rear plate 91 to enable the envelope 98 to have a sufficiently high strength for resisting atmospheric pressure.

25 [0164]

After fabrication of the phosphor film, the metal back 95 was made by smoothing the inner surface of the phosphor film (ordinarily called "filming") and by thereafter depositing Al by vacuum evaporation or the like.

[0165]

The face plate 96 further had a transparent electrode (not shown) provided on outer surface of the phosphor film 94 to improve the conductivity of the phosphor film 94.

[0166]

At the time of the performance of the seal-bonding mentioned above, it is necessary for opposing fluorescent materials of each color to the electron-emitting device in case of the color image-forming apparatus, and sufficient alignment is indispensable.

[0167]

In the present example, because the electrons to be emitted from the electron source were emitted to the gate electrode side, the fluorescent materials corresponding to the electron source were arranged to shift to the gate side by 200 μm in the case where the anode voltage was 10 KV and the anode distance was 2 mm.

[0168]

The scanning circuit 102 will be described. The scanning circuit 102 includes M switching devices (schematically shown as S1 to Sm in the figure). Each of the switching devices S1 to Sm selects one of the output voltage from a direct-current voltage source Vx and 0 (V) (ground level). The switching devices S1 to Sm are respectively connected to terminals Dx1 to Dxm of the display panel 101. Each of the switching devices S1 to Sm operates on the basis of a control signal Tscan output from a control circuit 103, and may be a combination of a switching device such as a field-effect transistor (FET) and other components.

[0169]

In this example, the direct-current voltage source Vx is configured to output a constant voltage such that the drive voltage to be applied to a device which is not scanned on the basis of characteristics of the electron-emitting device (electron emitting threshold value voltage), is not higher than the electron-emitting threshold value voltage.

[0170]

The control circuit 103 has the function of matching the operations of the components with each other to suitably perform display on the basis of input signals externally supplied. The control circuit 103

generates control signals Tscan, Tsft, and Tmry to the components on the basis of sync signal Tsync supplied from a sync signal separation circuit 106.

[0171]

5 The sync signal separation circuit 106 is a circuit for separating sync signal components and luminance signal components from an NTSC television signal externally supplied. This circuit can be formed by using an ordinary frequency separation (filter)
10 circuit, etc. The sync signal separated by the sync signal separation circuit 106 is formed of a vertical sync signal and a horizontal sync signal. However, it is shown as Tsync in the figure for convenience sake. Image luminance signal components separated from the
15 television signal are shown as DATA signal for convenience sake. The DATA signal is input to a shift register 104.

[0172]

 The shift register 104 is a device for serial to
20 parallel conversion, with respect to each image line, of the DATA signal which is input in time sequence. The shift register 104 operates on the basis of control signal Tsft supplied from the control circuit 103.
(That is, control signal Tsft may be considered to be a
25 shift clock for the shift register.) Data

corresponding to one image line after serial to parallel conversion (corresponding to data for driving N electron-emitting devices) is output as N parallel signals Id1 to Idn from the shift register 104.

5 [0173]

The line memory 105 is a storage device for storing data corresponding to one image line for a necessary time period. The line memory 105 stores the contents of the signals Id1 to Idn according to control
10 signal Tmry supplied from the control circuit 103. The stored contents are output as I'd1 to I'dn to be input to a modulation signal generator 107.

[0174]

The modulation signal generator 107 is a signal
15 source for suitably modulating signals for driving the electron-emitting devices according to image data items I'd1 to I'dn. Output signals from the modulation signal generator 107 are applied to the electron-emitting devices in the display panel 111 through
20 terminals Doy1 to Doyn.

[0175]

As described above, each electron-emitting device to which the present invention can be applied has basic characteristics described below with respect to
25 emission current Ie. That is, there is a definite

threshold value voltage V_{th} with respect to emission of electrons. Emission of electrons is caused only when a voltage higher than V_{th} is applied. When a voltage higher than the electron emission threshold value is applied to the electron-emitting device, the emission current changes according to changes in the applied voltage. Therefore, in a case where a voltage in the form of pulses is applied to the electron-emitting device, electron emission is not caused when the value of the applied voltage is lower than the electron emission threshold value, but an electron beam is output when the value of the applied voltage is equal to or higher than the electron emission threshold value. In this case, the strength of the electron beam can be controlled by changing the pulse crest value V_m . Also, the total amount of charge of the output electron beam can be controlled by changing the pulse width P_w .
[0176]

Therefore, a voltage modulation method, a pulse-width modulation method or the like can be used as a method for modulating the electron-emitting device according to the input signal. If the voltage modulation method is carried out, a voltage modulation type of circuit capable of generating voltage pulses having a constant duration, and modulating the pulse

crest value according to input data may be used as modulation signal generator 107.

[0177]

If the pulse-width modulation method is carried
5 out, a pulse-width modulation type of circuit capable of generating voltage pulses having a constant crest value and modulating the pulse width of the voltage pulses according to input data may be used as modulation signal generator 107.

10 [0178]

Each of the shift register 104 and the line memory 105 used in this embodiment is of a digital signal type.

[0179]

15 In this example, a digital to analog converter circuit, for example, is used in the modulation signal generator 107, and an amplifier circuit, etc., are added if necessary. For example, in the case where the pulse-width modulation method is used, a combination of
20 a high-speed oscillator, a counter for counting the number of waves output from the oscillator, and a comparator for comparing the output value of the counter and the output value of the above-described memory is used in the modulation signal generator 107.

25 [0180]

The configuration of the image forming apparatus described above is an example of the image forming apparatus to which the present invention can be applied. Various modifications and changes can be made
5 therein on the basis of the technical spirit of the present invention. The input signal is not limited to the above-mentioned NTSC signal. Those in accordance with the PAL system and the SECAM system and other TV signals corresponding to a larger number of scanning
10 lines (e.g., those for the MUSE system and other high-definition TV systems) may also be used.

[0181]

[Effects of the Invention]

According to the present invention, as described
15 above, the specific capacitance of an electron-emitting device can be reduced and the drive voltage can also be reduced. An electron source having improved efficiency and a smaller beam size can be realized by using such an electron-emitting device.

20 [0182]

Moreover, because an image forming apparatus according to the present invention is composed of the electron source, and forms an image on the basis of input signals, an image forming apparatus having higher
25 resolution, e.g., a color flat-screen television, can

be realized.

[Brief Description of the Drawings]

[Fig. 1]

Fig. 1 is a diagrams showing an example of a
5 basic electron-emitting device in accordance with the
present invention.

[Fig. 2]

Fig. 2 is a diagram showing a second example of
the present invention.

10 [Fig. 3]

Fig. 3 is a diagram showing a third example of
the present invention.

[Fig. 4]

Fig. 4 is a diagram showing a fourth example of
15 the present invention.

[Fig. 5]

Fig. 5 is a diagram showing fabrication steps in
a first example of the present invention;

[Fig. 6]

20 Fig. 6 is a diagram showing an example of an
arrangement for operating the electron-emitting device
of the present invention.

[Fig. 7]

Fig. 7 is a diagram showing an example of an
25 operating characteristic of the basic electron-emitting

device of the present invention.

[Fig. 8]

Fig. 8 is a diagram showing an example of the configuration of a passive matrix circuit using a plurality of electron sources in accordance with the present invention.

[Fig. 9]

Fig. 9 is a diagram showing an example of the construction of an image forming panel using the electron source of the present invention.

[Fig. 10]

Fig. 10 is a diagram showing an example of a circuit for the image forming panel using the electron source of the present invention.

[Fig. 11]

Fig. 11 is a diagram schematically showing the structure of a carbon nanotube.

[Fig. 12]

Fig. 12 is a diagram schematically showing the structure of a graphite nanofiber.

[Fig. 13]

Fig. 13 is a diagram showing a conventional vertical FE structure.

[Fig. 14]

Fig. 14 is a diagram showing an example of a

conventional lateral FE structure.

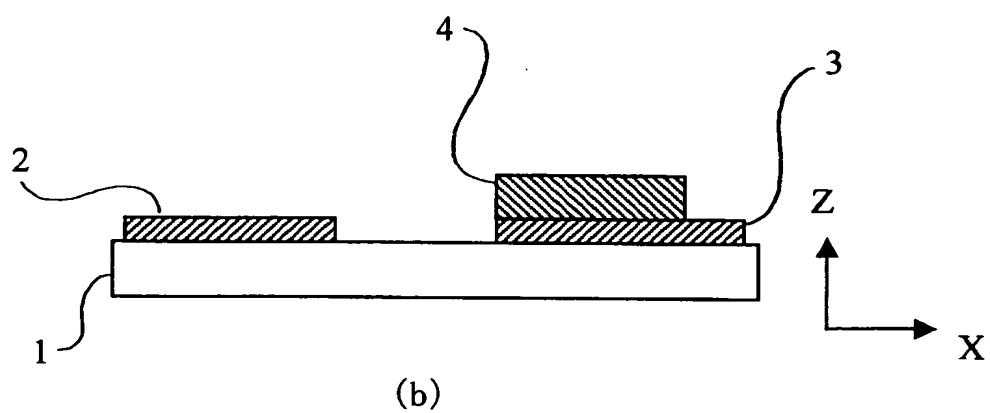
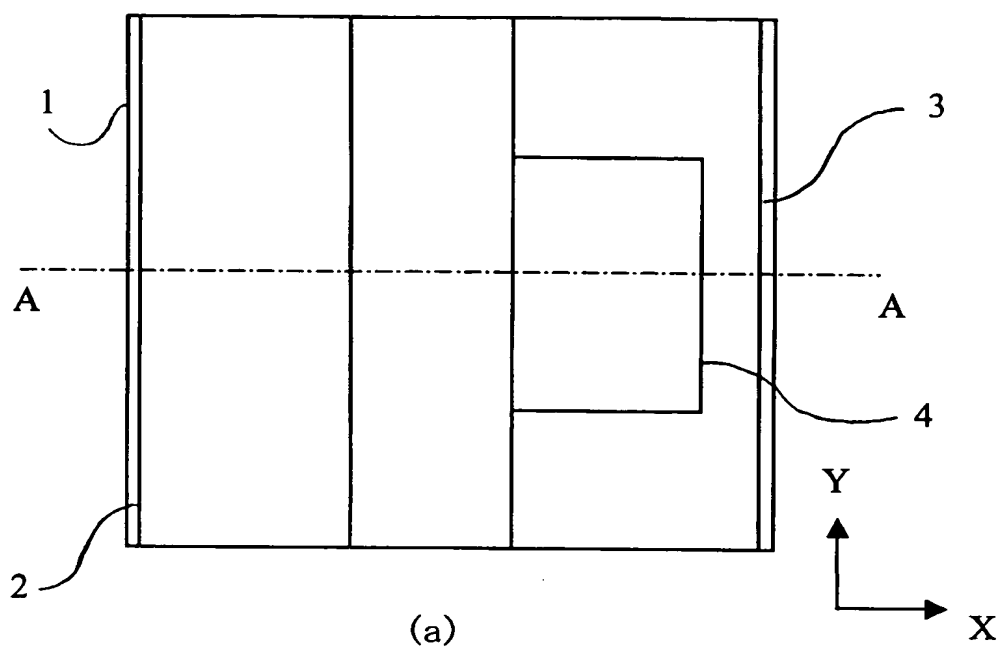
[Description of Reference Numerals or Symbols]

- 1 ... substrate
- 2 ... gate electrode
- 5 3 ... electrode
- 4 ... electron-emitting material
- 61 ... anode
- 81 ... electron source substrate
- 84 ... electron-emitting device

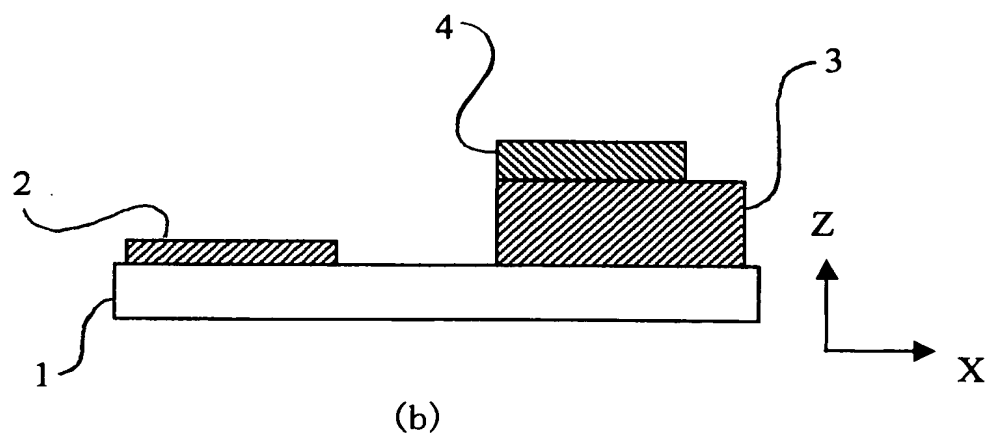
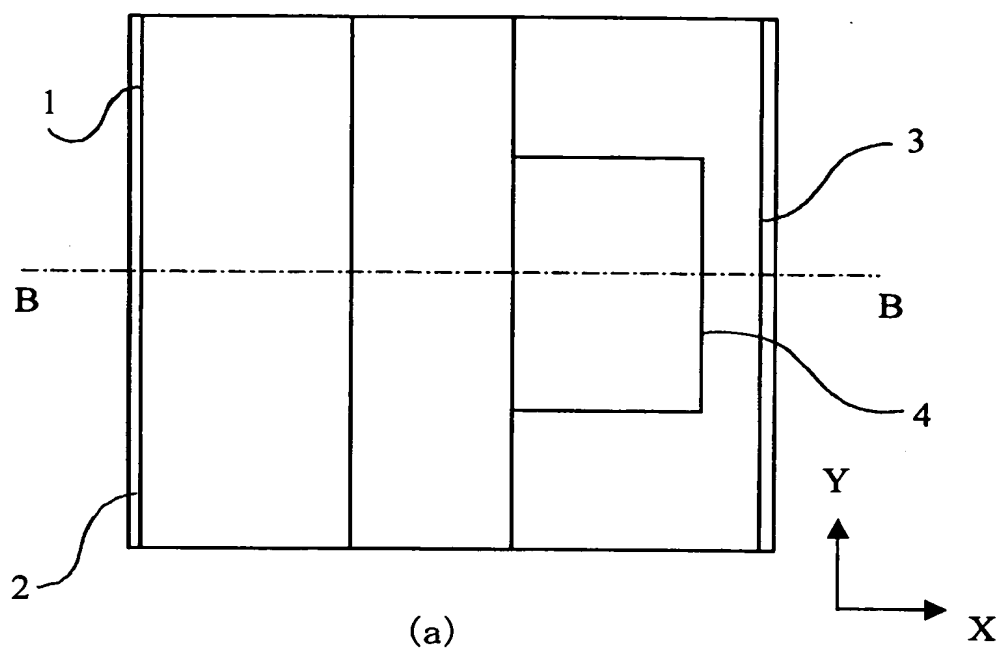
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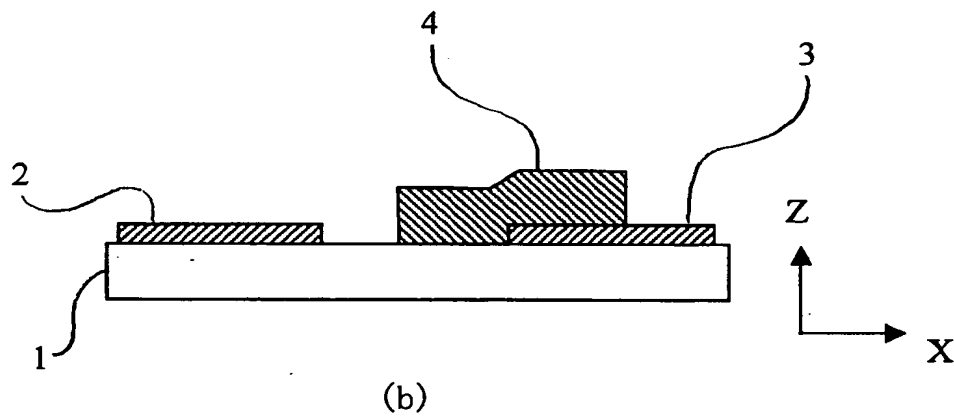
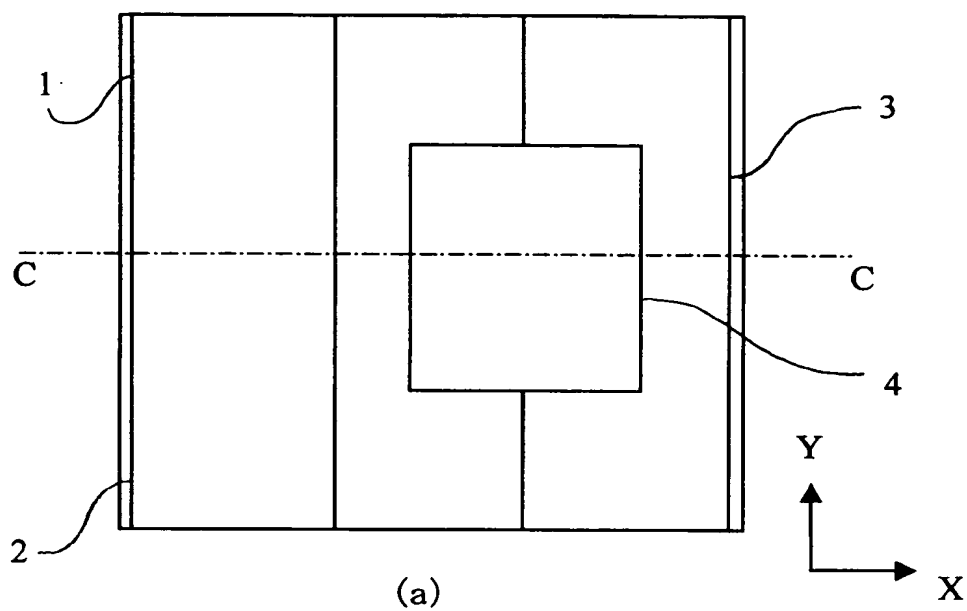
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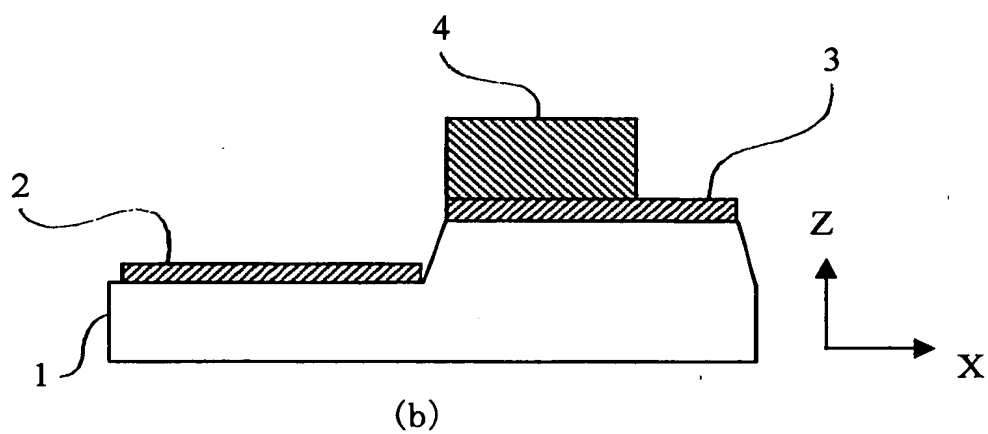
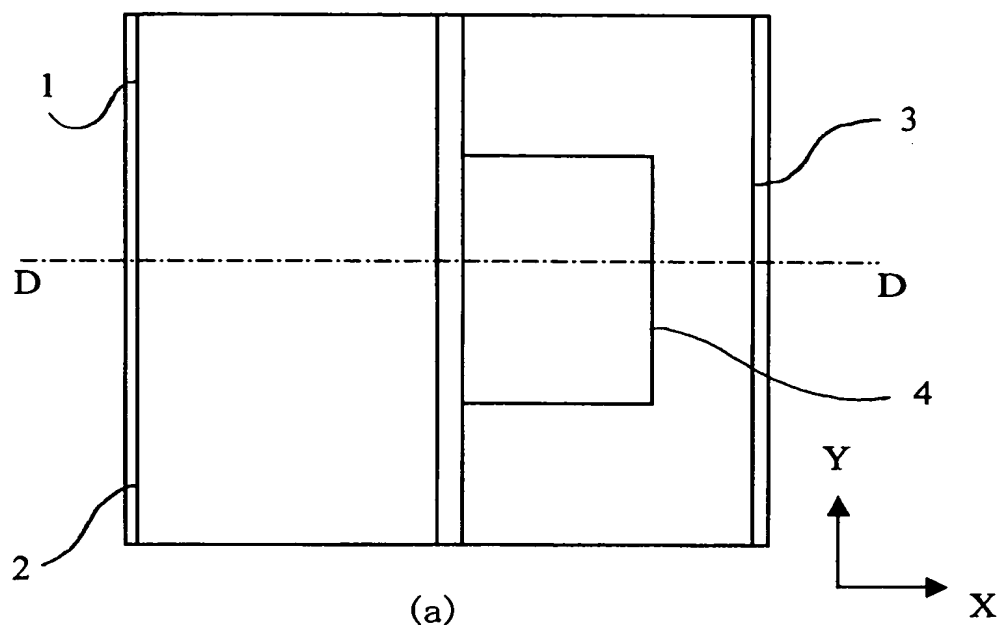
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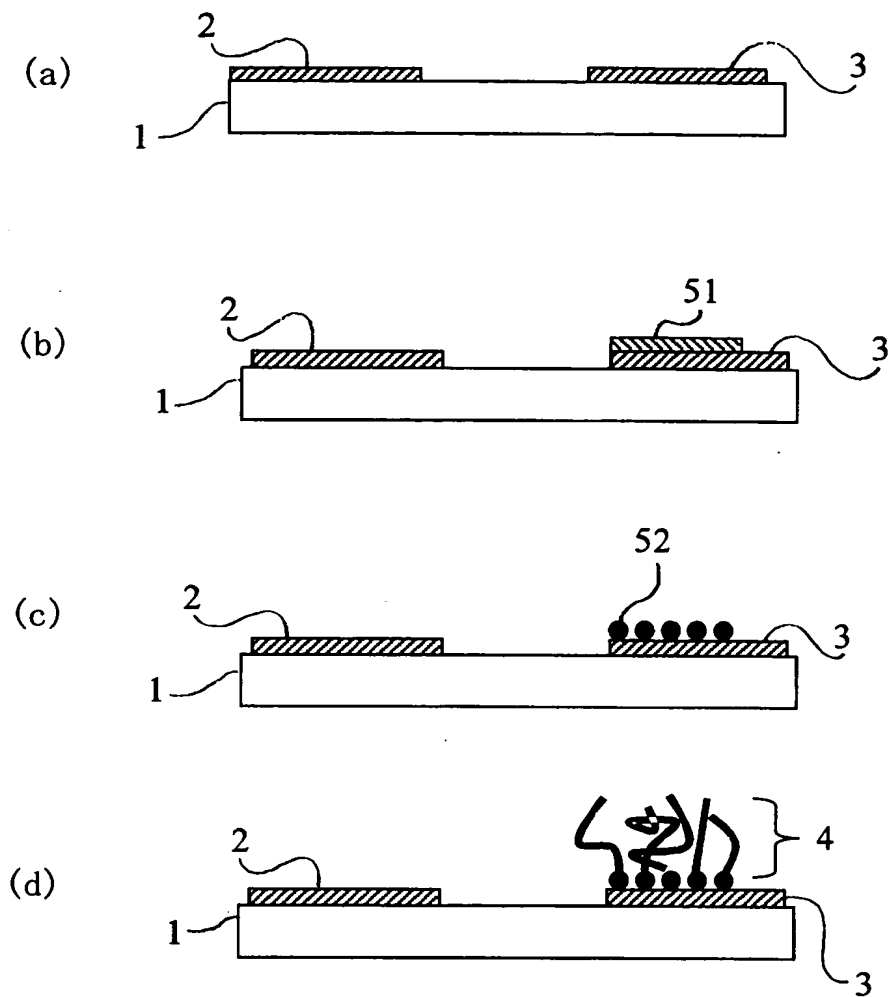
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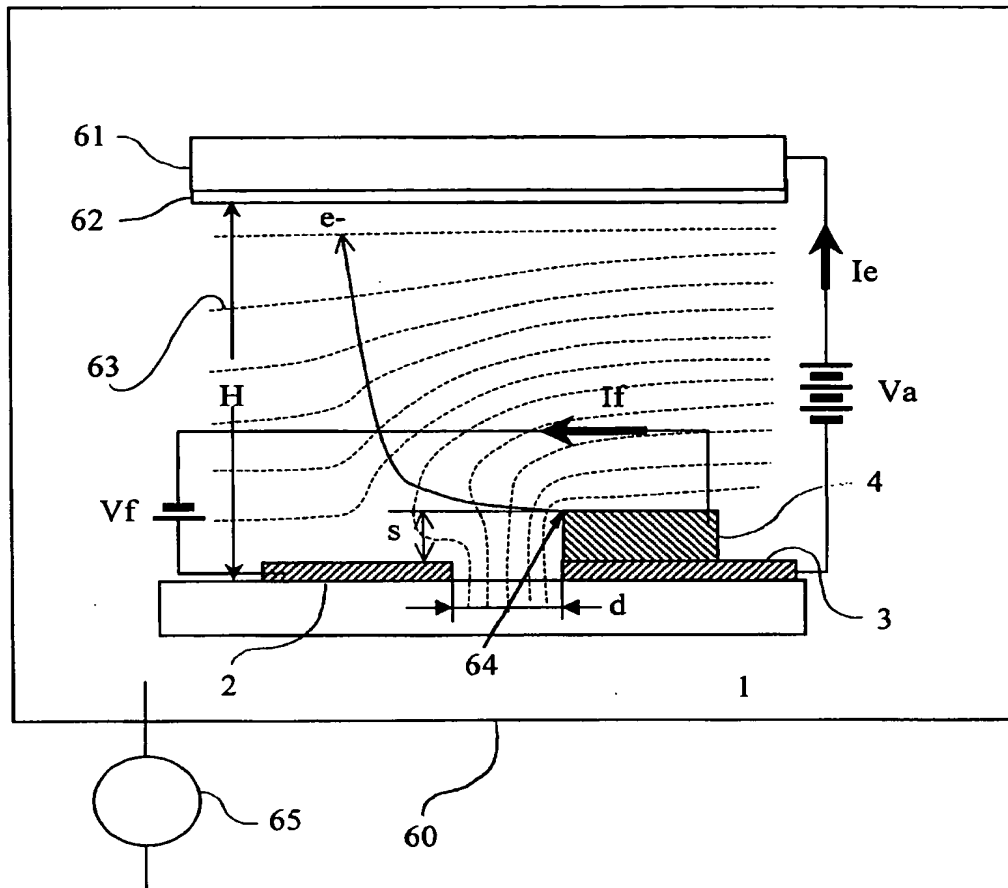
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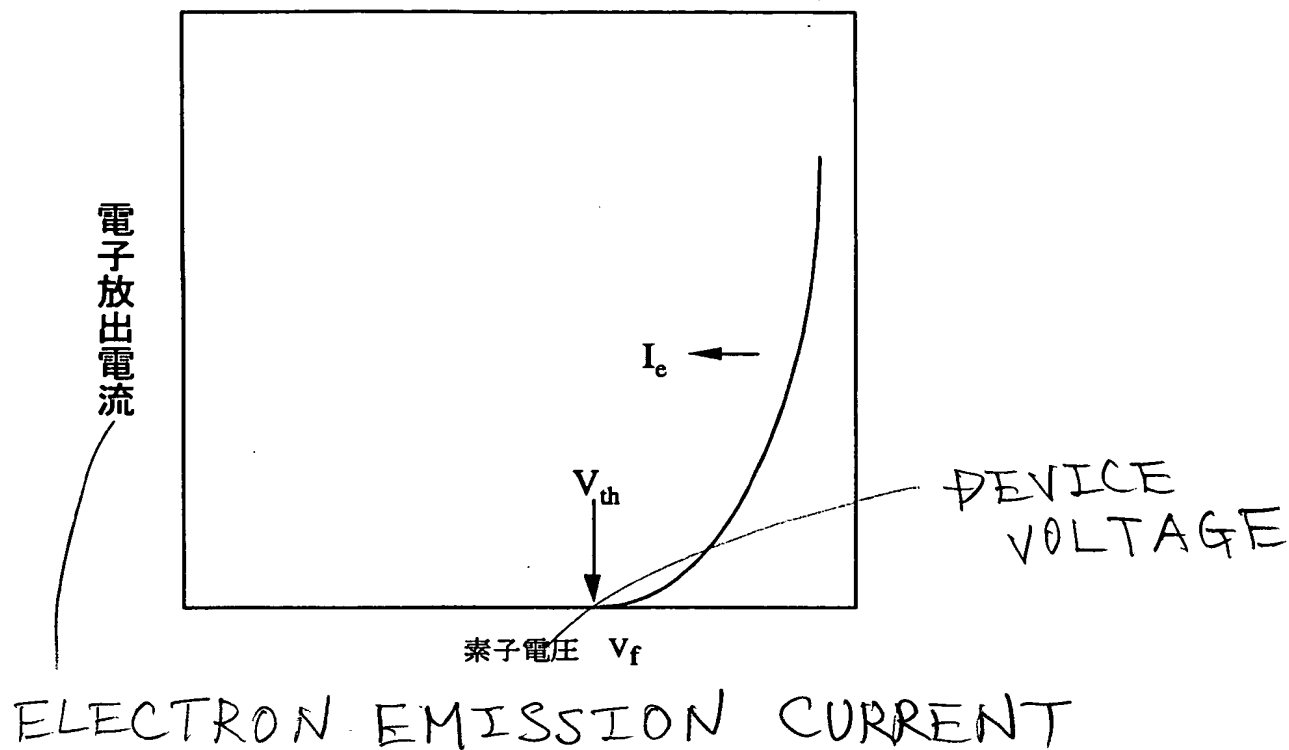
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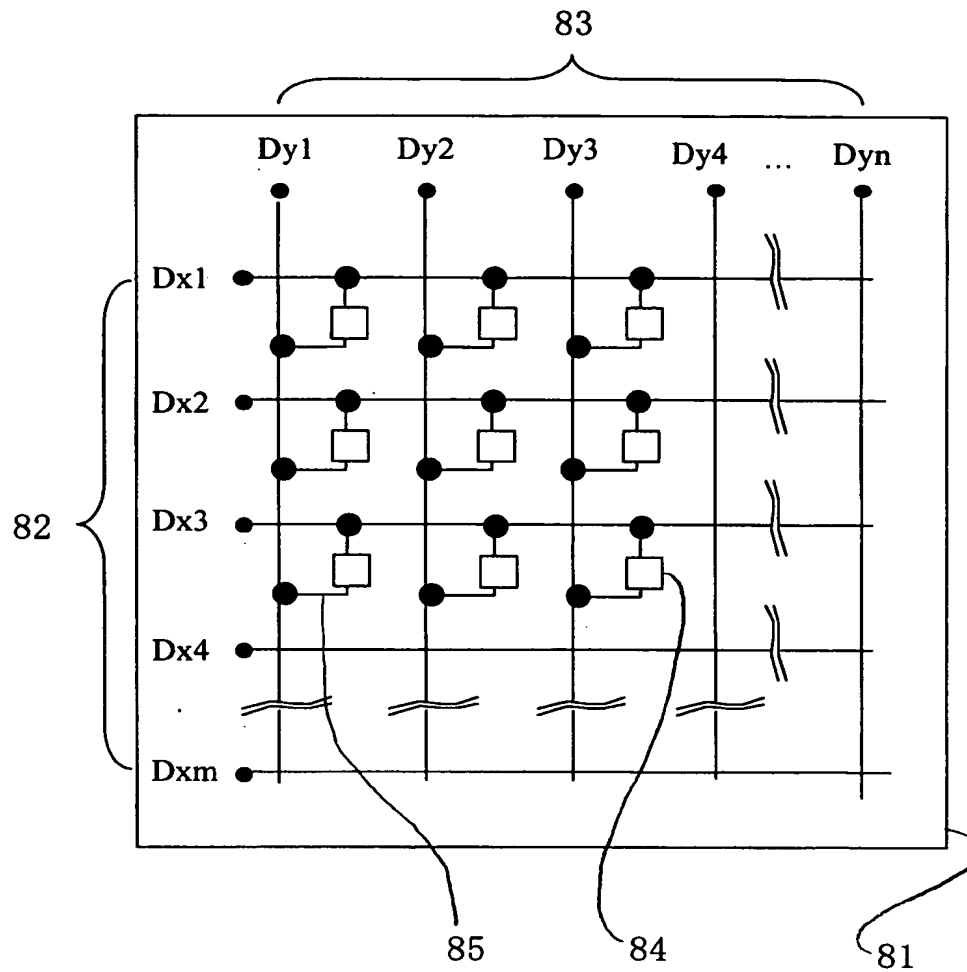
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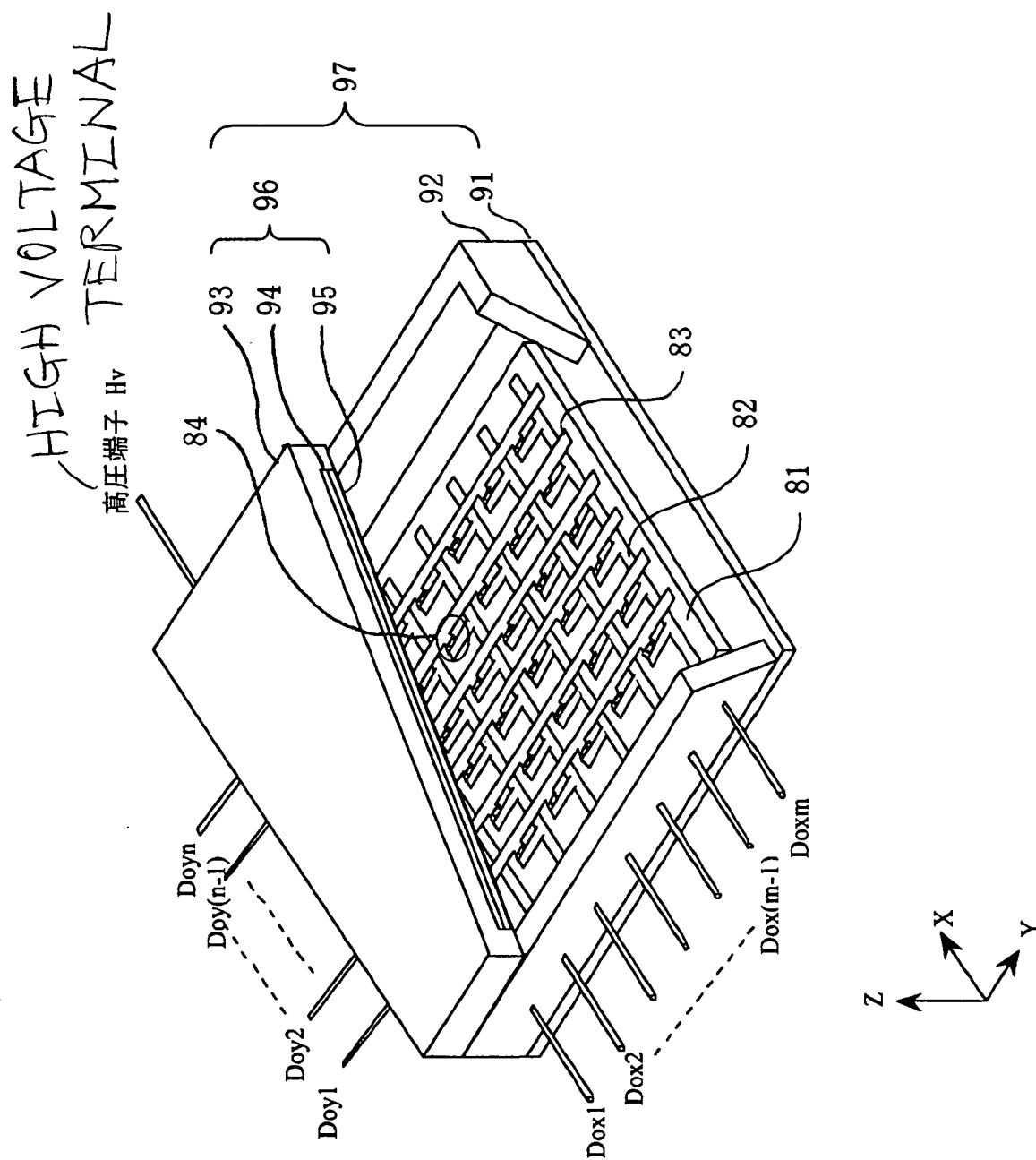
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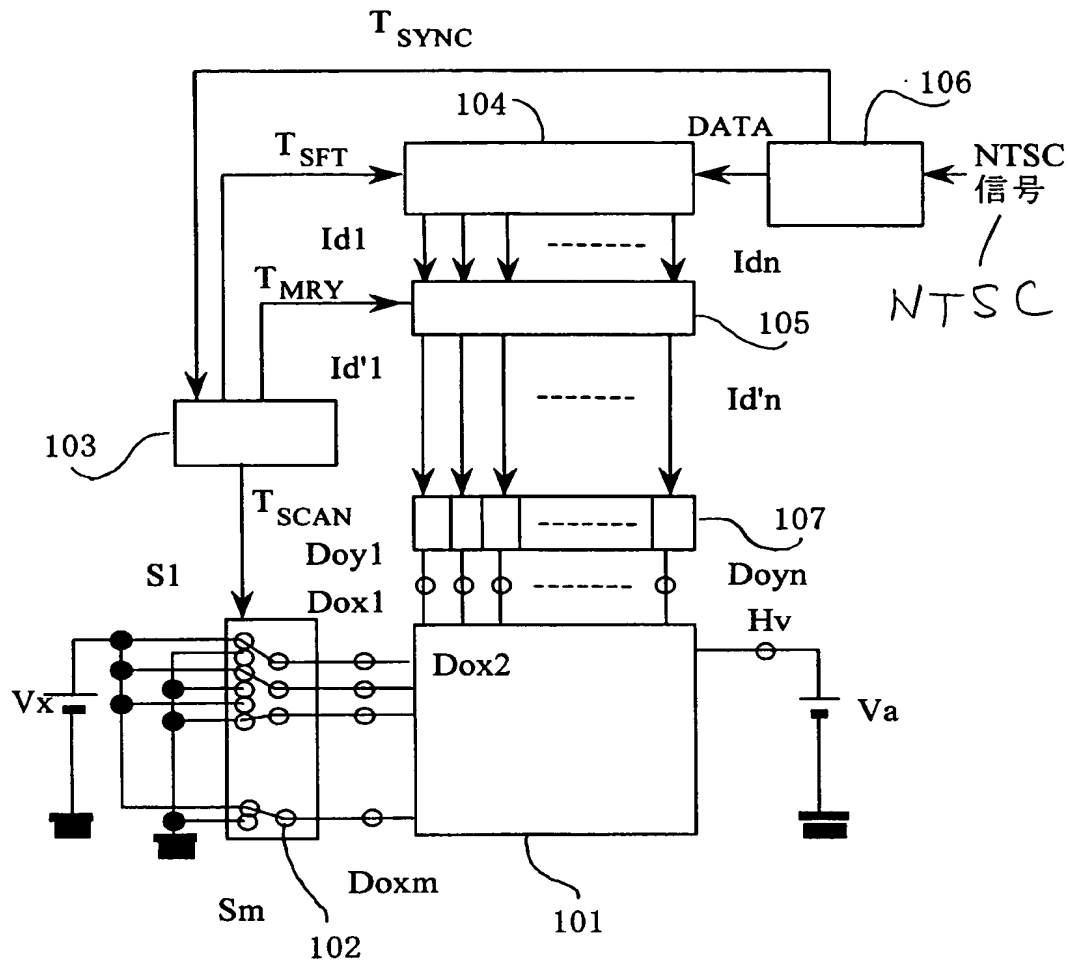
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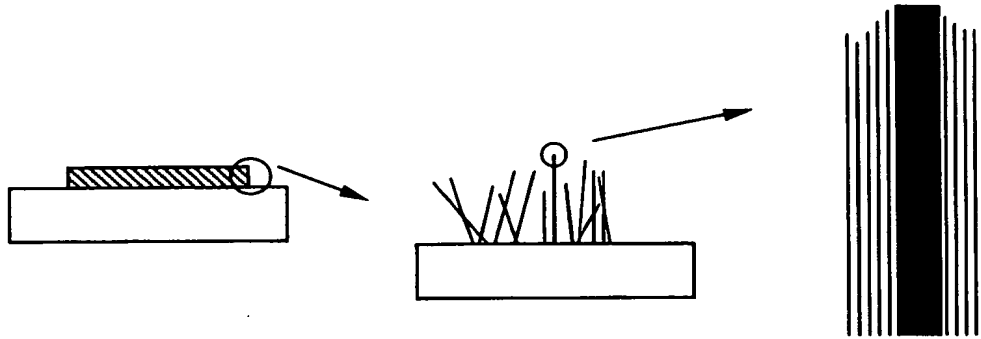
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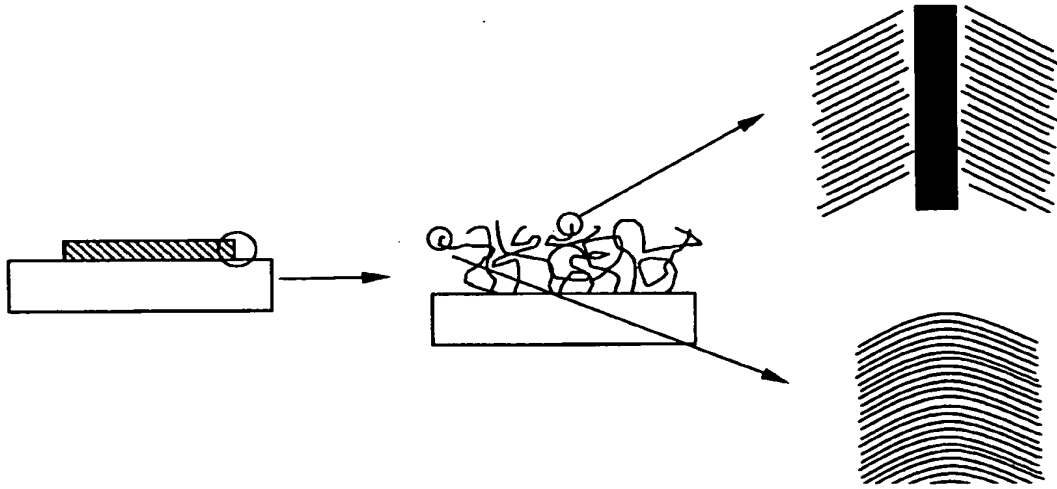
NTSC SIGNAL



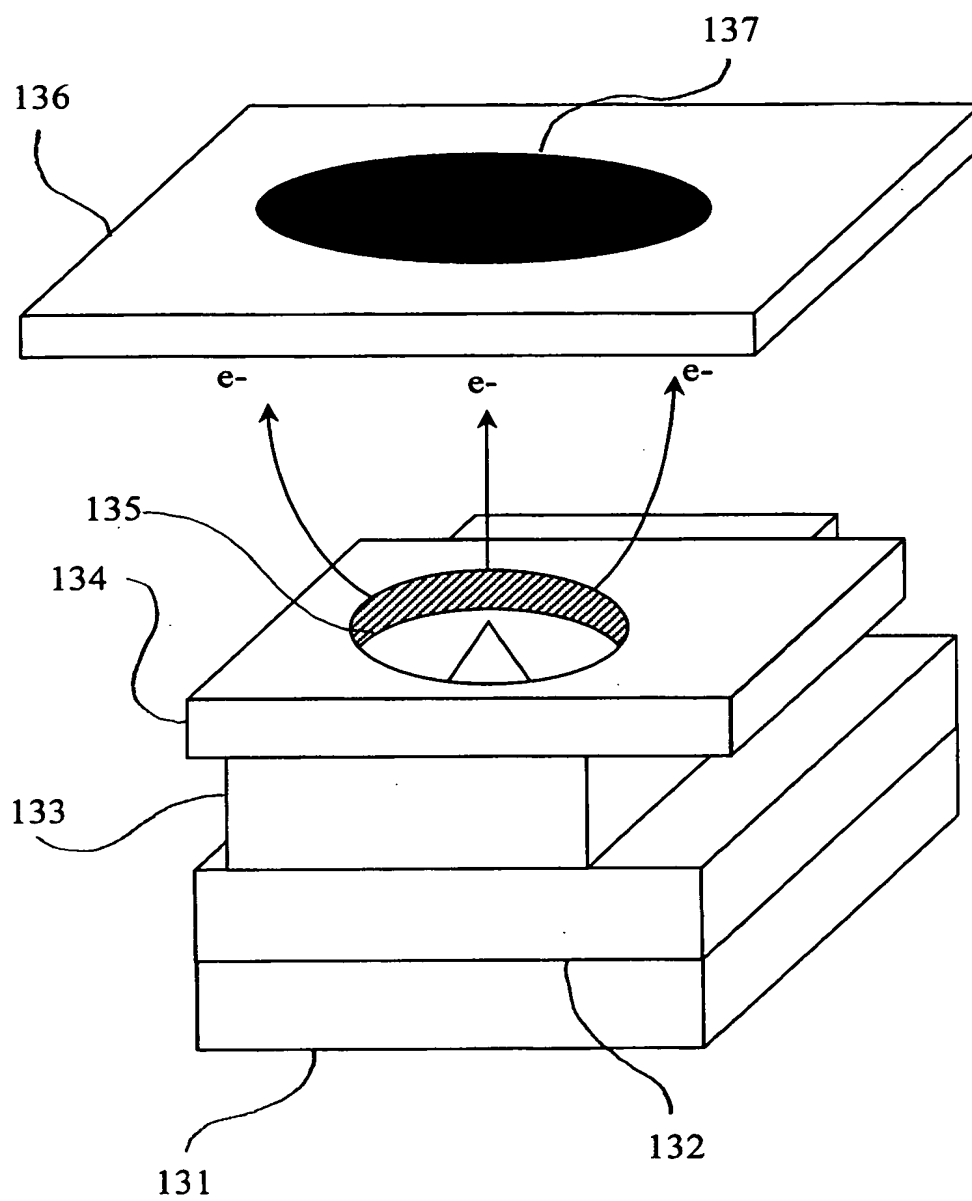
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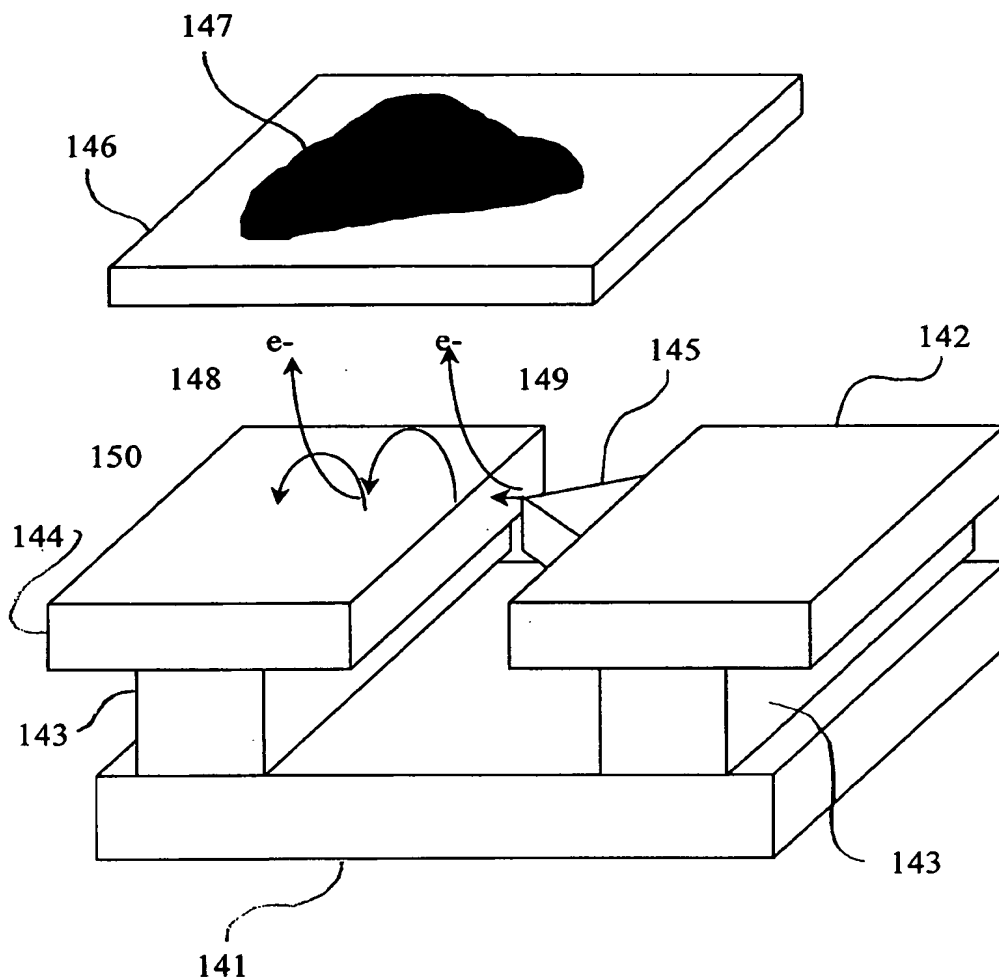
【図12】



【図13】



【図14】



[Name of the Document] Abstract

[Abstract]

[Object]

An electron-emitting device in which the specific
5 capacitance and the drive voltage are reduced, and
which is capable of obtaining a finer electron beam by
controlling the trajectory of emitted electrons.

[Means for Achieving the Object]

An electron-emitting portion of an electron-
10 emitting member is positioned between the height of a
gate and the height of an anode. When the distance
between the gate and a cathode is d ; the potential
difference at driving the device is V_1 ; the distance
between the anode and the substrate is H ; and the
15 potential difference between the anode and the cathode
is V_2 , then the electric field $E_1 = V_1/d$ during driving
is configured to be within the range from 1 to 50 times
 $E_2 = V_2/H$.

[Selected Drawing]

20 Fig. 6

2000-265819

Applicant's Information

Identification No. [000001007]

1. Date of Change: August 30, 1990

(Reason for Change) New Registration

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Certificate No. 2001-3083567